

DYNAMIC ASPECTS
OF
NUTRITION AND HEREDITY

FRANK HORRIDGE




22102049243

Med

K11905



DYNAMIC ASPECTS
OF
NUTRITION AND HEREDITY



Digitized by the Internet Archive
in 2016

<https://archive.org/details/b28087811>

53. C. 48

BRITISH MEDICAL
Library
ASSOCIATION

256

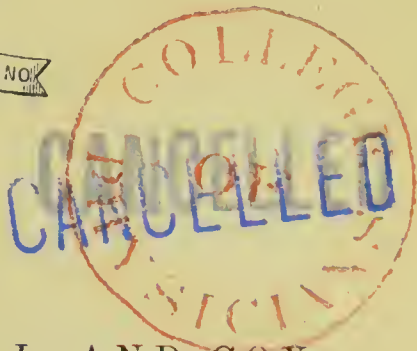
DYNAMIC ASPECTS

OF

NUTRITION AND HEREDITY

BY

FRANK HORRIDGE



256

LONDON

BAILLIÈRE, TINDALL AND COX

8, HENRIETTA STREET, COVENT GARDEN

1902

15 486 739

WELLS - STATE	
Full	Wulf D meo
Cap	
No	(3)

P R E F A C E

IN order to explain the elementary notions on which the theory of chemical combination is based it is customary to borrow illustrations from physics, and the latter science may in this sense be said to be the foundation of the former. In medicine and physiology physical considerations play an even more important part, for we have not only chemical action to deal with, but a number of rhythmical movements to take into account. With some of these we are already very familiar. With regard to others, however, and especially with respect to the rhythmical movements which take place in the nerve-cells, this is not the case. But since we know that the nervous system governs all movements, whether arterial, cardiac, respiratory, intestinal, or metabolic, we have at least a basis for conjecture, argument, and deduction. Even though direct evidence, strictly speaking, is unobtainable, we are still able to conceive the character of the action in the nerve-cells to some extent, and to draw inferences from the state and movements of the tissues. Between the former and the latter there must necessarily be a most intimate

degree of correspondence in regard to movement, for in this wide world of ours there is no government which does not rest upon a foundation of force, and the transmission of force implies action or movement. The reduction of chemical or physiological problems to a physical basis is, moreover, in some respects a process of simplification, and an endeavour to define the character of the movements which take place in the nerve-cells may be justified, if but partially successful, by the hope that it may ultimately lead to more direct and thorough methods of controlling them.

It is surprising to observe to what extent the physical or dynamic factor lies apparently at the root of some of the commonest and yet most important processes in medical practice. Indeed, to take a striking instance, it will probably have to be acknowledged, in default of any other equally credible explanation, that the immunity conferred by vaccination is, in reality, merely the result of a dynamic impression produced upon the nervous system. This will become to some extent apparent if we fully realize the meaning of certain characteristics of the nervous system, and the consequences of its relations to the whole organism.

To illustrate this, let us take a case. When some venturesome boy imprudently takes his first plunge in the practice of smoking by consuming one of his father's strong cigars, the result is usually such a revolution in his interior as to make him regret his

temerity for some time. Had he, however, begun with a whiff or two at a cigarette, and persevered for a week or so in giving himself up at intervals to this form of doubtful enjoyment, it is probable that he would at length have been able to withstand the effects of the stronger weed.

One fact stands out prominently in this example—viz., that it is the influence of a first impression even more than the actual strength of the tobacco which disturbs the functioning of the nervous system, and thus causes vomiting, headache, or whatever other consequences may follow. Other cases might also be cited to illustrate the same truth. Take, for instance, that of the opium-eater who accustoms himself by degrees to enormous doses, and thus, while weakening his nervous system, nevertheless acquires for it progressively immunity from the effects which would otherwise result therefrom.

How does the nervous system govern the metabolism of the tissues? There can, it would seem, be only one conceivable answer to this question: the nervous system must regulate all the various processes connected with tissue change by virtue of the force generated and developed in its own metabolism. Being the most readily mobile of all the tissues, the anabolic and katabolic changes in it give rise, we must suppose, to a continuous series of rhythmic movements the influence of which is felt throughout the body. The conditions essential to the perfect functioning of the whole system are, therefore, that

these rhythmic movements shall possess a given character, and that they shall be regular. These movements, however, are easily disturbed and rendered irregular. Thus, exposure of parts of the body simultaneously to two degrees of temperature, when sudden, is often, as we know, sufficient to upset the rhythm of cutaneous metabolism, and produce a cold. When bacteria in certain quantities enter the system there is a similar disturbance of rhythm. The nervous metabolic rhythm is one form of activity, the vital processes going on in the bacteria constitute another. Both the activity of the latter and their waste products bring about a change in the environment of the nervous system, and hence the disturbance. The capacity of an individual to resist the attack of an infective disease depends, one may say, on the power of the nervous system to preserve a certain regularity of rhythm in the presence of the bacteria, and, above all, to preserve a rhythm in which the excretory tendency is strongly accentuated. One may indeed compare the cells of the nervous system under these conditions to the members of a small settlement on which a party of savages has suddenly made a descent. If it be a matter of a first and unexpected attack, the excitement and confusion would naturally be greater than if it were a second or third occurrence of the same kind. So it is with the nerve-centres when bacteria of a virulent type invade the system for the first time. If they become, as they are likely to do, very excited, they lose in

part the regular and steady control which they previously exercised on the metabolism of the tissues, including the excretory processes, and thus the general vitality is diminished. But if after the first period of excitement the nerve-centres regain little by little their normal mode of functioning in the very presence of the bacteria, or if they have done so before in the presence of an allied but less virulent genus, a second attack is not likely to lead to the same degree of commotion and relaxation in the nerve-cells, or, in other words, to the same amount of disturbance in the nervous metabolic rhythm. When in vaccination the lymph is introduced into the arm, a local disturbance of the metabolic processes takes place. In a few days' time there may be swelling of the part and other signs of inflammation. As matters develop, especially if the case be severe, the effect becomes more general, and slightly feverish symptoms may be noticed. Thus both locally and as a whole the nervous system comes under this new influence. Its environment is modified, but in spite of the baneful character of this modification it continues to function. Within three or four weeks from the date of vaccination all the bacteria have been worsted in their attack upon the system. They have disappeared, being either absorbed by leucocytes or excreted by the usual channels. As an active force in the body they have ceased to exist. That anything of a tangible nature beyond the scar remains after the fourth week is indeed highly improbable, and as time goes on the

chance of any particle of the lymph being still left in the system grows ever less. Yet the period of immunity is generally recognised to be from seven to ten years. But if it is very difficult, or even impossible, to rest the case for vaccination upon a material basis, three facts in regard to it must strike one as undeniable: firstly, that the disturbance caused by it, lasting as it does for several days, must produce both a marked and a specific impression on the nervous system; secondly, that such impressions are likely to be of a very durable kind; and thirdly, that one such impression may modify considerably subsequent ones of like or allied nature.

Turning from preventive to curative medicine, we meet with an equally striking example of the employment of measures which are in reality of an essentially dynamic nature. For ages medicated baths of various kinds, containing salts, sulphur, iron, and other substances, have been adopted as a means of relief in certain pathological conditions, with results which, leaving success in the treatment of this or that disease out of the question, demonstrate, nevertheless, beyond all doubt that the physiological action of these remedies is not imaginary. Yet physiologists of repute tell us unhesitatingly that not one particle of iron or of salt or of sulphur ever enters the body through the skin. There is no absorption of these inorganic substances, so that if they act upon the system, as we know they do, they cannot act quantitatively, and therefore they must act dynamically—they must, that

is to say, modify the nervous rhythm. At first sight it may be difficult to conceive how this is brought about, for it is very improbable that there is actual contact between the nerve-endings and the salt or the iron contained in the bath. But if we suppose, as we have reason to, that a stratum of ether lies between the nerve-endings and the chemical substance, whatever it may be, that the nerve-endings are continually undergoing a certain delicate vibration due to the force generated in the nerve-cell in the process of its metabolism, and, further, that this force causes, as it were, waves or impulses in the stratum of ether which dash up against the particles of salt or iron and come back bearing the character of these substances and thus transmitting it to the nerve-endings and through them to the nerve-cells, then we shall understand how the nervous rhythm may be modified and the physiological processes depending on it altered, although nothing whatever has been added to the body. We can also comprehend how it is that even an insoluble drug, such as calomel, can produce so marked an effect, and how an insoluble preparation of arsenic, such as dentists commonly use, causes death in the nerve of a tooth. Transmission in such cases is, moreover, very similar to the phenomenon of sight if we suppose light itself to be due to ethereal movement.

In speaking of the action of insoluble drugs and of chemical substances held in solution in baths as being of a dynamic nature, only a very limited portion of

the truth has, however, been stated, for there is probably no exaggeration in saying that the effects produced by all chemical compounds which act directly on the nervous system are mainly of the same kind. These compounds do not give rise to quantitative changes; they do not alter the chemical composition of the bodies of which nerve-cells are formed, although they may contribute materials for the purpose of building them up. A little alcohol, we may suppose, has passed from the digestive organs into the blood, and has finally reached a nerve-cell. Its presence undoubtedly modifies the environment of the cell, and influences its molecular movements, its metabolic rhythm, in the same way as the salt or the sulphur does that of the nerve-ending. But if the alcohol be broken up into carbon, hydrogen and oxygen, its specific action must at once disappear. If we were to imagine chemical compounds as acting on the nerve-cells quantitatively, then we should have to conceive the tissue of the cell as being ready to absorb at once, within certain limits, any quantity of carbon, hydrogen, oxygen, or nitrogen which might be offered to it, and one's apparently well-grounded belief in the constancy of the chemical composition of the chief bodies contained in nervous matter would melt away. When, therefore, we have on the one side variability in the chemical composition of the constituents of the nerve-cell, together with quantitative changes therein, and on the other side constancy in the chemical composition of these constituents, together with dynamic

variations in the environment of the cell as alternative explanations of modifications in the character of nervous action caused by food or drugs, it is towards the latter theory that the balance of probability inclines. Even in the case of simple elements a superabundance is not only sometimes useless, but may be highly prejudicial. Phosphorus, for instance, though a constituent of nervous matter, when given in moderately large doses, far from contributing to the building up of the tissues, rather increases the katabolic tendency. The building up of our tissues depends, one may say, less on the quantities of the materials provided than on the play of those dynamic influences whereby metabolism in the nervous system and through it in the whole body is governed.

Though the chemical processes of metabolism are both varied and complicated in the highest degree, yet in all of them certain physical factors, such as the simple forces of attraction and repulsion, play, there is reason to believe, an essential part. We may note the influence of these forces in the contraction and expansion of vaso-motor action, we may infer it in other instances of physiological action also, and by keeping it always in view we may hope to penetrate the mysteries of some problems which, when considered without making due allowance for this factor, must remain insoluble.

In dealing with the subject of the functions of the cerebellum too many pages have perhaps been given up to the consideration of the anatomy of the spinal

cord, and the only justification for this lies in the intimate relations which exist between the cerebral and cerebellar systems. For this and for other shortcomings, due not only to the complicated nature of the subject, but to personal deficiencies, I must ask for the reader's indulgence. To express scientific truths with any degree of completeness is always a very difficult matter, and this is especially the case in the domain of physiology, where the factors with which one has to deal vary more than in other sciences.

February 3, 1902.

CONTENTS

CHAPTER I

	PAGE
THE ACTIVE FORCES OF LIVING ORGANISMS - -	1

CHAPTER II

THE SPINAL CORD AND THE FUNCTIONS OF THE CERE-	
BELLUM - - - - -	96

CHAPTER III

HEREDITY - - - - -	157
--------------------	-----

DYNAMIC ASPECTS OF NUTRITION AND HEREDITY

CHAPTER I

THE ACTIVE FORCES OF LIVING ORGANISMS

The invisible factor—Vortex atoms—Queries and guesses—The omnipresence of matter—Matter is essential to conduction—Attraction and repulsion are essential to rigidity—The conducting medium in gravity—The vibration of atoms—The ether permeates all matter—The reaction of atoms on the ether as a possible cause of electrical potential—The ether as a transmitting medium in vegetal reproduction—Properties of the ether—Tension of the ether as a factor in electrical conduction—Ether or light substance as the transmitting medium of light—Vision an ether sense—The effect of colours on the emotions—The two scales—The cell and the nucleus—The cause of the nucleus in the blood corpuscles of birds and reptiles—Nuclein, protagon and lecithin—The relatively small amount of oxygen in the cerebral compounds determines the nature of their metabolism—The cerebral circulation—The effect of some drugs on oxidation—Alcohol—Strychnine—Dynamic effects—Physiological antagonism—Action and reaction—The apparent effect of drugs on the gray matter—The nature of physiological reaction—Some factors in metabolism—The selection of materials by the tissues—The degree of oxidation going on chiefly determines the nature of the compounds—The

negativity of oxygen—Muscular contraction is a process of deoxidation—Conditions most favourable to anabolism—The contractility of nerve-cells—Variations in the tension of the ether as the cause of the current of action in a nerve-fibre—The influence of functional activity on metabolism—The influence of contraction and expansion on oxidation—The nature of the nervous impulse—Electrical vibration is always connected with chemical or with molecular vibration—The three elements—Electrical phenomena—Electricity intensifies the effect of the conditions under which it is administered—Electricity as an almost neutral agency—The effects of high altitudes—Mountain sickness—The chief points—The importance of the nervous factor—The relative diminution of carbonic acid and oxygen in the blood—The effect of variations in the relative amount of these gases—Effects of diminished atmospheric pressure—Diminution of chemical intensity in high altitudes—Observations on individuals in the Alps—Experiment to demonstrate the effect of carbonic acid on the respiratory movements—The composition of the blood in high altitudes—The influence of a place may be transmitted through the ether—Some results of massage—Contractility—The influence of pre-existing conditions—Application of the theory of the ethereal nature of electricity to physiology—Views of French physiologists on electro-motory action—The transport of atoms in an electrical cell and in the body—Absorption in the amœba—The concatenation of automatic actions and reactions in digestion—Chemical action as a cause of nervous impulses—Secretory or chemico-sensory nerves in the submaxillary gland—Direct stimulation of the chemical processes—Relative independence of electro-chemical action and nervous action in metabolism—Difference between secretory action in the submaxillary gland and in the stomach—All nerves and nerve-cells are concerned in chemical action—Heat and cold in their relation to nervous action and metabolism.

MATTER and force are the finite elements into which any substance, whatsoever be its nature, is divisible. Hitherto in biological science attention has been so

closely riveted on the former that the latter has never really emerged from the obscurity of the background.

The reason of this is not far to seek. Force is the <sup>The invis-
ible factor.</sup> one factor in the calculations of modern research which escapes our ken, the impalpable element in all our problems, the unknown quantity, the eternal X in the algebra of science. It appears in many guises—as wind, water, steam, light, heat, chemical energy, molecular vibration, sound, magnetism, nervous impulses, and electricity, now gathering its units into a single wave, now scattering them over a broad expanse, sometimes storing itself up with slow and steady progress, anon bursting forth into rapid and violent shocks, transforming itself with surprising suddenness, according to the conditions of the media through which it passes, always in a sense active, always invisible, and yet never really lost. Assuredly what little we know of such a phenomenon is sufficient to make us attribute to it the greatest, most extensive, most unforeseen powers, and to lead us to suspect its action in those mysterious physiological processes which without it are, and must, remain inscrutable, impenetrable riddles. In an investigation such as that which lies before us we shall see it in many phases, carving, moulding matter, and being in turn acted on, directed, modified.

There is no more interesting theory with respect to the constitution of matter than that of Sir W. Thomson, which consists in regarding atoms as little masses of ether always in motion, as differing,

in fact, from the rest of the ether only in the modes of motion to which they are subjected. Such whirling portions possess rigidity through the very fact of their motion,* so that we may say with truth that force, which is merely another name for the motion of matter, is the very essence of matter. It is the cause and origin of all material substances.

This idea has been rendered more easily comprehensible by the observation of vortex rings. These are produced by giving at a certain moment to every atom in a plane disc of a fluid a velocity which should be graduated according to its distance from the edge of the disc.† If you take a box, over one side of which a piece of stuff is tightly stretched, whilst in the opposite side a circular hole is cut, and, after filling the box with smoke or other visible fumes, tap smartly on the covered side, a vortex ring may be clearly observed sailing through the air.‡ Its properties are interesting. In the first place, it has become differentiated from the rest of the air by the application of external force of which it has become the embodiment. It has remarkable stability; the core is elastic and possesses rigidity. When one vortex ring impinges on another they are deflected in their course, and vibration occurs. It is on somewhat similar lines that atoms are supposed to be formed, and hence they are called vortex atoms.

* Lodge, 'Modern Views of Electricity,' p. 416.

† Lodge, *loc. cit.*, p. 412.

‡ Wurtz, 'The Atomic Theory,' pp. 326-328.

The bare statement of such a theory as that of vortex atoms brings a host of questions to one's lips. ^{Queries and guesses.} If this be true of the atom, is it not true of the world also? Is not a world a collection of atoms, just as a crowd is a collection of individuals? and does not a crowd behave in a general way, though perhaps with greater intensity, as a single individual does? If atoms are mere collections of ether, is their permanence relative or absolute? Are we right in supposing them to be eternal, to have had no beginning and to have no end? Or, on the other hand, are they the result of forces in the ether itself—forces acting within a given space, it may be, for trillions of years, and yet not eternal in that space? Can we attribute eternity to atoms and not to worlds? Can we take such a stand positively, remembering that vortex movement is but one phase of motion or force? If the force implied in the vortex movement of atoms be really and solely intrinsic, how are we to explain the fact that all ether does not resolve itself into atoms? May we not conclude that in every sufficiently great volume of ether there is a tendency towards the formation of a focus due to more or less equal pressure on all sides? May we not suppose that the rotational movements of stars and atoms alike are the result, in the first instance, of pressure of this kind? Motion, within certain limits, is, we may assume, the property of infinitely divided matter, such as the ether. All that is wanted, therefore, is a certain condition of things which shall give that motion direction. The

celestial bodies may be looked on as foci of ethereal force, each one of them reacting to some extent upon those nearest to it. If we adopt this view, do we not obtain an inkling of the causes which have determined the existence of so great a variety of atoms—a variety which is reproduced in so striking a manner in the most distant corners of the heavens? Deny these causes, and, since hydrogen is known to exist in the furthest nebulae, one must suppose that all matter was once united in one huge mass, a conception appalling to the imagination of the veriest Atlas amongst philosophers. Moreover, if we regard each kind of atom as a particular degree of force embodied in ether, we can imagine to some extent how its vibrations in chemical action give rise to nervous and other forms of force.

The omni-
presence
of matter.

For a long time a belief has been entertained that beyond the limits of our own atmosphere nothing remained but empty space. But of recent years this opinion has been frequently called in question, and many of our foremost thinkers have now become so materialistic in their view of things as to conceive the hitherto inconceivable notion that ether itself is a form of matter, that it is to be found everywhere, and that empty space is simply non-existent*—at least, so far as the universe is concerned. What there may be beyond the universe, supposing it to embrace all that we are ever likely to see with the most powerful telescope, need not trouble us very much. Even

* Lodge, *loc. cit.*, p. 379.

those who for the sake of a theory would push deductive investigation forward into regions so distant will do well to remember that the absence of tangible signs of matter does not justify the assumption of its non-existence. Its infinite divisibility and omnipresence are, indeed, conceptions which we can no longer afford to disregard.

The view that ether is really matter in the finest state of division appears to be confirmed by certain simple reflections. Matter in some form is either absolutely necessary for the conduction of light and heat or it is not. If we adopt the view that it is essential, we must conclude that all forms of force constitute a jostling of infinitely small particles, for we can have no conception of force otherwise than as matter in motion. We shall then be led to suppose that both heat and light are merely modes of motion communicated to the free ether, and from it to the bound ether of atoms and of matter in general. But electricity has within recent years been found to bear a very close relationship to light, which is, indeed, held to be an electrical phenomenon.* There appears,

* Lodge, *loc. cit.*, p. 377: 'The main proof of the electro-magnetic theory of light is this. The rate at which light travels has been measured many times, and is pretty well known. The rate at which an electro-magnetic wave disturbance would travel, if such could be generated, can be also determined by calculation from electrical measurements. The two velocities agree exactly.'

[If the ether be the common medium by which the light wave is, and the electro-magnetic wave might be, transmitted, the equality of velocity is, to some extent, explained. The fact

therefore, to be some reason for supposing electricity also to be, like heat and light, a mode of motion of ether.

Matter is
essential
to conduc-
tion.

This way of looking at things has, moreover, the advantage that it enables us to understand why, as is so often the case, one form of force is suddenly transformed into or gives rise to another—heat to light, chemical action to heat and electricity. If, on the other hand, we put aside the theory that force is always a mode of motion of matter, it will be seen at once in what an argumentative quagmire we are landed, for we should then be obliged to imagine it as existing *per se*, and apart from matter, which means that it would be produced out of nothing. Such a conception, to say the least of it, transcends the powers of human comprehension. Nevertheless, the idea of empty space is so ingrained in our nature, owing to the limited range of our senses, that it will be long before it is completely banished from our minds, as banished it must one day be, if we are to form correct views of the universe.

Once having subscribed to the theory that atoms are little whirling masses of ether, one is naturally inclined to go a step further, and to draw certain deductions. The infinitesimal particles of which we must suppose each atom to be composed are, so long

that electricity in its usual form travels still faster may perhaps be accounted for either by the absence of wave movement or by other conditions affecting the medium of which we are ignorant.—F. H.]

as their corporate existence lasts, all subjected to a common form of motion. This motion is the cause of or constitutes the rigidity which is the essence of the atomic form. Rigidity implies two things: it implies a certain degree of attractive power and a certain degree of repulsive power. Chemistry teaches us that these powers exist—that they are, in fact, the basis of all the interchanges comprised under the term ‘chemical action.’ Now, if we remember ‘that every substance in the universe attracts every other substance with a force jointly proportional to the mass of the attracting and of the attracted body, and varying inversely as the square of the distance,’* we pass at a single stride from the atomic theory to the law of gravity, from the atom to the world or collection of atoms.

Attraction and repulsion are essential to rigidity.

Since, however, we have already come to the conclusion that no conduction of force can take place save through the medium of matter, we must suppose that, when an apple falls to the ground, either force has been transmitted to it from the earth through the medium of the air or the ether, or that it has come under the influence of force proceeding from the ultra-mundane ether, and affecting it, the earth, and all that appertains to it in common. But in the attraction exerted by one heavenly body on another the atmospheric air may be left out of account, and the ether remains as the sole medium for the transmission of attractive force.

The conducting medium in gravity.

* Balfour Stewart, ‘Physics,’ p. 44.

The vibrations of atoms.

It will, of course, be borne in mind that the predominance of attractive power over repulsive power is an essential condition of the existence of atoms. Were the latter greater than the former vortex, motion could no longer continue, and with its cessation the rigidity peculiar to matter would disappear, and the bound ether of the atom would become free. We may perhaps suppose that when chemical action takes place, as it always does, owing to some external force, such as light or heat or electricity—that is to say, to a movement of some kind of the ether—the perfect vortex motion is momentarily modified, that there is, as it were, a slight tendency on the part of the bound ether of the atoms to become free, to vibrate in unison with the disturbed ether surrounding them, and, reacting on it, to communicate to it a portion of the force which in the quiescent state is more entirely internal.

The ether permeates all matter.

Not only do physicists look upon ether as filling all space between our earth and the other heavenly bodies, but they also suppose it to permeate all matter surrounding atoms and filling up whatever vacuum would otherwise be left between them.

The reaction of atoms on the ether as a possible cause of electrical potential.

This view is of interest for many reasons, and amongst others because it seems to suggest a partial explanation of the electrical differences which exist between various substances; for, if we consider electricity to be a mode of motion of the ether, we may assume that all atoms when excited by a vibration of the latter would not react with the same

degree of intensity, and one might speak of those which react with greater vigour as being of higher electrical potential than those whose reaction on the ether was weaker, or was attractive rather than repulsive. When a current of electricity is passed through certain substances so as to set up chemical action, it is evident that the attractive or repulsive properties of the atoms so affected are brought into play. Similarly, when the molecules of any substance, such as sealing-wax, are excited by rubbing, it possesses attractive or repulsive power, according to the stuff or substance with which it is rubbed and with which it is brought into relation. The phenomenon of gravity tends to show that the attractive power of matter may be communicated to the ether, and through the ether to other bodies. Matter in that case is in its normal or quiescent state, and it seems natural to suppose that when it is excited, as it is by rubbing, its effect upon the ether would be far greater. If, therefore, two substances be rubbed together, we might suppose that each would communicate to the ether permeating the other something of the character of its atoms or molecules. Something of this kind seems to occur when a pith-ball is touched by excited glass or excited sealing-wax. The ether permeating and surrounding the ball may be then supposed to act as a medium of attraction or repulsion, according as the sum of the atomic and molecular influences brought to bear on it agrees or disagrees with the sum of the influences proceeding

from the other substance brought within range. If this be true, not only does the dual fluid theory disappear, but we obtain in addition a clue to the mysterious processes of natural reproduction; for if the ether is able to transmit influences from such a substance as a piece of excited sealing-wax to a pith-ball, and, so to speak, to impress to some extent its character upon it, we are justified in supposing the same medium might carry an influence or impulses from the excited root or the excited leaf of a plant to the equally excited seed. Further, the potential or latent force stored in the latter supplemented from without gives to the seedling its special form and character. If in connection with the subject of heredity transmission there be one truth deserving attention more than another, it is that force is always the moulding agent of matter, or, in other words, that the form of matter can only be modified by matter in motion.

In speaking of anything of so impalpable a nature as the ether, there is always some risk of attributing to it, for the purposes of any argument, characteristics which it does not really possess. At the same time, however, our knowledge of it may perhaps be increased by considering it in its relation to certain natural phenomena, and by carefully examining and comparing the consequences of our general conceptions of it. Thus, it is frequently said that the ether constitutes an all-pervading, indivisible medium. This latter property has been recently cited as a proof that the ether is not the medium by which waves of

The ether
as a trans-
mitting
medium in
vegetal
reproduc-
tion.

Properties
of the
ether.

light are transmitted, for it has been argued that an absolutely indivisible medium cannot be thrown into waves. The weakness of this argument seems to lie to some extent in the fact that use is made of words generally employed to represent finite ideas to describe that which is essentially infinite. In the first place, it is evident that the ether is divisible by the molecules and atoms which move and have their being in it; but, on the other hand, it will be seen that a medium, consisting of matter in a state of infinite division, must of necessity be in a certain sense indivisible. It is a case of *les extrêmes se touchent*. The air around us may in a more limited manner be said to be at one and the same time both infinitely divided and indivisible. We shall probably obtain a more correct idea of the ether if we attribute to it in a still higher degree many of the properties of air with which we are familiar. Amongst these we may mention two which are of importance, the first being the property of being thrown into waves, and the second that of conducting impressions from one substance or collection of molecules to another. That the ether possesses this latter property in a very high degree we may believe; for the more matter is divided, the less do the particles of which it is composed possess any individuality, and the more readily do they obey any impulse they may receive.

There is a second property of the ether which may be said to be evolved out of its all-pervading nature and its conductivity, and this is tension.

Tension of the ether as a factor in electrical conduction.

The air, to return again to the more familiar example, is always in a state of tension, irrespective of its weight. If you take a vessel from which the air has been withdrawn and make an opening in the bottom, it will naturally fill again as rapidly as if the aperture had been in the top. But the tension of the ether is far greater than that of our atmosphere. Now, if we suppose a number of molecules or of molecules and atoms to be vibrating at a given point A—to be hammering, that is to say, the ether—and another lot to be hammering it, though in a different manner, at a given point B, let us say, it is evident that when the general tension of the ether is taken into consideration, conditions favourable to an interchange or discharge of impulses might be said to exist. Certain media—such, for instance, as a copper wire—may be used to isolate a stratum of the ether between any two points, and thus to render communication the more easy. When, however, a suitable apparatus is raised to a certain height above the ground, so as to be removed in all probability from the ethereal influence of the earth and objects on it, even the use of a connecting wire, as Marconi's experiments have shown, is unnecessary.

Ether or
light sub-
stance as
the trans-
mitting
medium of
light.

Those who refuse to adopt the view that light is transmitted by means of the ether are, nevertheless, obliged to base their conception of it on the existence of a second medium, called by them light substance, which in its chief properties of divisibility and ubiquity so closely corresponds to one's notions

of the ether as to be, practically speaking, inseparable from it.

Although what we know of the physiological action of light does not appear to furnish us with a clue to its origin, yet there are certain points in connection with it which are of interest. If, for instance, we look upon the ether as the medium by which light waves strike the eye, then we must perforce recognise it as playing the part of an initiating agency in one of the most important of all physiological processes. Further, if the ethereal movements coming from without start physiological action, it seems impossible to withstand the conclusion that the ether within the body may also in a very marked degree contribute to, if not originate, processes of a similar nature.

It has often been remarked that certain colours give rise to different emotional states. The colour red is often spoken of as a warm tone, and, when vivid, causes in us what one may term an emotional glow. In the turkey-cock and bull this effect is much more pronounced, and assumes the character of furious rage. Yellow brightens the feelings, dazzling on the whole rather than exciting. Green awakens emotions which approach those caused by yellow, and yet are more subdued; it cheers and soothes at the same time, the effect varying as it inclines towards yellow or blue. The latter colour has a distinctly tranquillizing effect, and the results obtained by those who have had practical experience in the treatment of disease by light baths tends to corroborate this

Vision an
ether
sense.

The effect
of colours
on the
emotions.

The two
scales.

statement, affording proof also that the red rays are the most exciting. Violet is, as is well known, the colour used in royal funeral ceremonies, and is decidedly calming. Thus, we have, as it were, a scale of colour and a scale of emotions, and it will be seen that in discussing them we have passed from one end of the spectrum to the other in the order in which the various kinds of light are arranged according to the length of their waves. One cannot believe this to be mere hazard, and this agreement between the two scales becomes of greater interest when we reflect that the character of our emotions is probably dependent on the mode of vibration of the molecules of the nerve-cells. The movements of the latter depend directly, it is true, on the intensity of certain oxidation processes in the retina, but these in turn are doubtless influenced in varying degrees by the shade of the light by which they are started.

The cell
and the
nucleus.

In order to obtain a comprehensive view of many of the most mysterious phenomena of life, it is very important to consider the nature of the nuclei of cells. Within recent years it has been said that every cell either has, or at some time had, a nucleus. This statement has been put forward rather as an article of belief than as a fact due to actual knowledge. In certain unicellular organisms—such, for instance, as the yeast plant—the existence of a nucleus has frequently been doubted, but those who hold to the opinion of its omnipresence allege that the particles of which it is composed must become disassociated

during or previous to the act of observation. This reasoning might possibly apply to some cells, but it could not be advanced to explain the lack of a nucleus in the red corpuscles of the blood of mammals. The only way out of the difficulty would seem to lie in the contention that the red corpuscles are not cells in the proper sense of the term. But though this may be true, what are we to say of the red corpuscles of the lower animals, which are distinctly nucleated? How can we explain this peculiarity, bearing in mind that a nucleus is recognised by all observers to be the most essential part of a cell? Are we to classify the one set of corpuscles as cells and not the other?*

One might at first sight be inclined to connect the presence or absence of a nucleus with the rate of tissue-change, since very many of the creatures possessing nucleated corpuscles belong to the cold-blooded class, whose vital functions are strikingly slow. Thus, a salamander can live without food for six months; a toad for two, and fresh-water polypi for five or ten years; whilst a snail, after six weeks of abstinence,

The cause of the nucleus in the blood corpuscles of birds and reptiles.

* Quain's 'Anatomy,' p. 29: 'The affirmation of Bottscher that a nucleus is present in the mammalian red blood corpuscle rests entirely upon erroneous methods of preparation. That of Stricker (which is a revival of the older opinions of Wharton Jones, and of Busk and Huxley), that the mammalian red corpuscle is, morphologically, a nucleus with an imperceptible amount of enveloping cell-substance, is quite distinct from Bottscher's view, and has certain considerations to recommend it, but is supported at present upon an insufficient basis of fact, and is opposed, moreover, to recent observations upon the development of the red disc.'

only loses about an eleventh part of its weight.* But, on the other hand, birds possess nucleated corpuscles, and yet they of all animals are the first to suffer from want of food, whilst their respiration is of a very intense nature. One day's total abstinence, it is affirmed, will kill a sparrow, three days a thrush, the respiratory intensity, as measured by the relative quantities of oxygen absorbed and carbonic acid and nitrogen exhaled, being seven times greater in birds than in mammals, whilst that of the latter is ten times that of reptiles. It does not, therefore, seem to be possible to establish any connection between the presence of the nucleus and the rate of activity of the vital processes. On the other hand, however, there seem to be some reasons for supposing the development of the nucleus to be inversely proportional to that of the nervous system. The nucleus is by common consent a centre of vitality for the cell. If we estimate the vitality of the tissues in the lower animals by the readiness with which portions separated from the organism reunite with it—as, for instance, in the case of an earthworm, or by the long-continued twitchings to be observed in a spider's legs when cut off from the body—we shall be inclined to conclude that life in these and similar types is less centralized than is the case with mammals in general. A parallel to these conditions may be found in institutions of human origin; for as the central authority in any country increases, the power of the individual as

* Letourneau, 'Biology' (trans.), p. 147.

steadily diminishes. These considerations do not, it is true, go to the root of the matter, for no definite statement can be made until the conditions under which the red corpuscles are manufactured are more clearly known.

The analysis of the substance of the nuclei of cells by various observers shows that nuclein, its chief ingredient, contains the elements carbon, hydrogen, nitrogen, phosphorus, and oxygen. The results obtained on different occasions do not, unfortunately, allow the proportion in which they occur to be fixed with absolute certainty, but the following formula* may be taken as showing approximately the amount of each: $C_{29}H_{49}N_9P_3O_{22}$.

It is interesting to compare this formula with those of two of the chief constituents of the brain,† viz., protagon ($C_{160}H_{308}N_5PO_{35}$) and lecithin ($C_{44}H_{90}NPO_9$). In the first place, we see that, though these three substances are built up on somewhat similar lines, since they each contain nearly twice as much hydrogen as carbon, and small amounts of nitrogen and phosphorus, yet nuclein contains a relatively considerable amount of oxygen. This fact points to the conclusion that the amount of oxygen present, or, at any rate, the degree of oxidation going on during its formation, is greater than is the case when in their respective localities of origin protagon and lecithin are formed. Lecithin, it is true, is a substance which

Nuclein,
protagon
and
lecithin.

* Foster's 'Physiology,' Appendix, Sheridan Lea, p. 88.

† *Ibid.*, pp. 134-137.

is found in many parts of the body, amongst others in muscular tissue and in red blood corpuscles, and its presence in these regions may seem to contradict that which has just been said. But it must be borne in mind that the formation of any substance, and its appearance in a given locality, may be totally separate events, and it is very probable that those localities in which red blood corpuscles are formed—such, for instance, as the cancellous tissue of bone—are not seats of active but of restricted oxidation. The supply of blood in the red marrow is abundant, it is true, but the flow of blood is slow, and there is very little movement of any other kind. If we suppose lecithin to be formed in such a region, the supply of phosphates in the bone itself would seem to be a not improbable source whence the minute quantities of phosphorus required are drawn. Whatever be the truth in regard to this point, it is evident that, when such substances as lecithin and protagon are formed, which are, comparatively speaking, poor in oxygen, this gas must in some way be kept in the background.

The composition of the three bodies above mentioned is such that, if broken up, the amounts of each of the elements carbon and hydrogen would be able to combine separately with, or absorb more—and in the case of the cerebral compounds very much more—than, the quantity of oxygen present. It is a very debatable point whether, in addition, the presence of phosphorus renders these compounds more than usually liable to become oxidized. With respect to

the behaviour of this element in the animal economy opinions differ greatly. Some look upon its presence in the brain and elsewhere as without any special meaning; others are disposed to regard it as a factor of importance in vital processes. That it is a very active element is undeniable, and although in certain insoluble or slightly soluble compounds this activity may disappear, yet there is no reason to suppose that it plays a quiescent or secondary part in cerebral matter, in the nuclei of cells and in the yolk of egg. These are at all times centres of great activity, and it seems improbable that the element phosphorus, which in the free state has so great an affinity for oxygen, should remain inactive at such moments, or even relatively so. Some authorities hold that, after severe mental exertion, the amount of phosphates in the urine is increased. By others this is denied. Although on general grounds one may suppose the former to be in the right on this point, yet, if the amount of phosphorus liberated during cerebral action is at all in proportion to the quantity of carbonic acid formed, any increase of the former due, as there is reason to suppose, to the breaking down of lecithin* would be very slight. Sometimes, however, when abnormally large quantities of phosphates are present in the urine, it is not improbable that this is due to a greatly relaxed condition of the tissues in general and of the bloodvessels to the nerve centres, whereby metabolism

* Foster, *loc. cit.*, p. 651.

is carried on under conditions of excessive oxidation and of loss.

The relatively small amount of oxygen in the cerebral compounds determines the nature of their metabolism.

In respect to the nature of metabolism in the cerebral and other nerve centres, one feature deserves special attention. The composition of the chief compounds which go to make up the brain and spinal cord, or those parts more properly called nervous matter—of lecithin, that is to say, and protagon—is such that, however rapid metabolism may be, the actual degree of oxidation in a healthy subject is very limited. As already remarked, the amount of oxygen compared to the other elements which they contain is, indeed, so small that they are incapable of absorbing much of that gas when forming, or of producing much carbonic acid when breaking down. When the venous blood from the brain is compared with that proceeding from a muscle, it is found to contain much less carbonic acid. Both the white matter of the brain and muscle contain a large proportion of water, the amount being 70 per cent. in the former and 75 per cent. in the latter. But the chief constituents of cerebral matter, such as protagon, cerebrin, and lecithin, contain more carbon in proportion to the amount of oxygen which enters into their composition than does the proteid of muscle; they also contain vastly more hydrogen, and, excluding the nuclei of muscular tissue, more phosphorus, though probably less nitrogen. The amount of oxygen in proportion to the carbon present being more in muscle than in the substances just mentioned, it is natural that the

quantity of carbonic acid given off in metabolism should be greater—in other words, oxidation in the muscles, which compose so large a portion of the entire organism, is more intense than in the brain and spinal cord, or, to put it in another way, the nervous system compared to the muscular system, and in all probability compared to the viscera also, is an area of restricted or limited oxidation. On the other hand, if we are justified in estimating the readiness to oxidize by the relative amounts of oxidizable elements, such as carbon, hydrogen, and phosphorus, and by the degree in which they are already oxidized in muscle and in brain matter, then it is the latter which appears to have the keener appetite.

When it is remembered that the nature of the metabolism in the nervous system probably governs that taking place in the tissues, the necessity of ascertaining the degree of each, and the relations which they bear to one another, will at once be evident. The belief that one cannot oxidize too much is, indeed, a very common one nowadays, but in view of the facts already mentioned it is one which requires a considerable amount of qualification, especially in those cases in which the bloodvessels to the nerve centres, either through hereditary or other causes, expand and contract too freely upon stimulation. Stoking is doubtless all very well, but it is necessary not to forget the damper; and whilst we possess a multitude of methods of stimulating oxidation, we have none by means of which it can be regulated.

The cere-
bral circu-
lation.

If we take the brain as a whole, one of the most remarkable points in connection with it is the small amount of the blood-supply. The actual amount of blood in the brain of a rabbit is hardly more than 1 per cent. of that in the whole body.* It is but one-half of that which might be extracted from the kidneys, whilst in the liver there is more than twice as much again.† The cortical supply is, however, probably more abundant than that to the white matter, and since the cortex in the rabbit is but ill developed, the low percentage above-mentioned may to some extent be accounted for in this way. In man we may suppose that the quantity of blood flowing to the gray matter bears a slightly higher proportion to the rest, but at the same time it is none the less true that the quantity of oxygen absorbed and of carbonic acid formed—or, in other words, the intensity of oxidation under normal conditions of activity—is governed by the chemical composition of the substance of the brain. When allowance, therefore, has been made for the difference in the development of the cortex in the rabbit and in man, there are still reasons for regarding the nervous system as a whole as an area of relatively limited oxidation. Cerebral circulation is, indeed, slackened and restricted at the very outset by the extreme sinuosity of the arteries. It is said that this is in order to prevent any too sudden or violent flow of blood to the cerebral centres, the consequence of which might be dangerous. But this is

* Foster, *loc. cit.*, p. 1239.

† *Ibid.*, p. 1239.

evidently the effect and not the cause of this sinuosity, which can be best explained by supposing a naturally sluggish flow and certain conditions of physical resistance to have existed in the course of development. Moreover, the brain of all the viscera is that which undergoes least massage through bodily movements, and the absence of this stimulus may be looked on as one of the causes of the restricted character of oxidation in nerve centres. In all metabolism there are two principal factors, one of which is the blood-supply and its state of oxidation, whilst the other is movement in the tissue, which is both molecular and atomic.

The action of certain drugs upon the nerve centres illustrates in a curious manner the delicate nature of the mechanism, the key to which is oxidation in a given degree. The primary effect of a moderate dose of alcohol is to quicken the heart's action, to increase indirectly the contractility of the muscles, and to

The effect
of some
drugs on
oxida-
tion*
alcohol.

* It will be borne in mind that the effect of a drug on the substance of nerve-cells, or on protoplasm in general, and its effect, especially its primary effect, or its effect in small doses on the organism, are often really opposed to one another. Drugs which diminish oxidation in protoplasm, considered *per se* by constricting it, cause at first an increase of contractility in the heart and vascular system, and hence indirectly, and within certain limits, produce an augmentation of oxidation. At the same time, the ultimate effect of such drugs—that is to say, the reaction of the system—after they have ceased to act, is in general opposed not to the indirect effect they produce, but to the direct effect on protoplasm. It is for that reason that, in the remarks which follow, attention has been chiefly directed to the latter.

stimulate the nerve centres.* If the dose be augmented, a very marked slackening of the vital processes occurs. The general consequence of large amounts of alcohol is said to be to arrest oxidation by imprisoning the oxygen in the blood corpuscles, thus impeding the transfer of it to the tissues.† Just as sleep produces a decrease of oxidation, so conversely a diminution of oxidation when caused by alcohol leads to drowsiness and sleep. Alcohol itself is a product of what one may term incomplete oxidation, for when more completely oxidized it gives rise to ethyl aldehyde and water, to acetic acid and water, or to carbonic acid and water. Until it combines with what oxygen it can seize, it appears to produce a chemico-dynamic effect—it seems to strike a note of incomplete oxidation, of the state, that is to say, in which it was produced. It is not impossible that its stimulative effect in the first instance is due, not, as has been supposed, to an increase of oxidation, but to a slight decrease. A change in the degree of oxidation is probably always a stimulus to nervous action, for the molecules of the nerve-cells may be supposed to vibrate in a different manner, the rearrangement which they undergo constituting excitation to increased movement. That a diminution of oxidation is attended by increased nervous excitability is conclusively proved by the phenomena of asphyxia, in the first stage of which the heart's action is increased.

* Mitchell Bruce, 'Materia Medica and Therapeutics,' pp. 155, 156.

† *Ibid.*, p. 155.

Another important drug which probably acts by ^{Strychnine.} diminishing oxidation, not perhaps in the tissues generally, but in the nerve cells, is strychnine.* A fact of considerable interest in connection with this alkaloid is that it is produced in the nut called nuxvomica by an arrest of the oxidizing processes which are going on in it,† so that when it acts upon man it may be said to transfer the chemico-dynamic state directly from the vegetal to the animal kingdom, and in this state it is the degree of oxidation which is apparently of most importance. Like alcohol in small doses, though in a far greater degree, it stimulates muscular contraction and nervous activity in general. The effect of alcohol depends on quantity in a much higher degree than is the case with strychnine. One can scarcely believe that the latter robs the blood of an appreciable portion of its oxygen. It appears, indeed, to strike a certain note, a note of diminished ^{Dynamic effects.} oxidation, and to cause the molecules of the nerve centres to vibrate to this tune. The more stable it is—and strychnine is supposed to be relatively a very stable compound—the longer will it make its presence felt dynamically. All the most powerful drugs may be supposed to act dynamically rather than by virtue of the quantitative chemical changes they produce.

* See p. 25.

† Letourneau, 'Biology,' p. 114. They (proteic substances) also furnish—but by incomplete oxidation, by degradation—asparagin, of which we have spoken, and, without doubt, the vegetal alkaloids (quinine, morphine, strychnine, etc.), quaternary, but not proteic, substances.

It is not easy to understand how a drop or two of such a poison as prussic acid (HCN) can kill as it does, unless it be that the absence of any oxygen, and the presence in it of hydrogen, carbon and nitrogen, cause a note of arrested oxidation to be struck even more pronounced than is the case with strychnine. The fact that prussic acid, when produced in the course of nature, is found hidden away in the kernel of a hard peach-stone certainly suggests a state of diminished or arrested oxidation.

Physio-
logical an-
tagonism.

Drugs are sometimes said to be physiologically antagonistic which are not really so in their mode of action, or are so only in a limited and partial manner. Thus strychnine ($C_{21}H_{22}N_2O_2$) is spoken of as the physiological antagonist of physostigmine ($C_{15}H_{21}N_3O_2$), and may be used as an antidote in poisoning by that drug. Yet the action of the two is in some important respects similar: both produce constricting effects, and are used in constipation. If we look at the matter from the dynamic point of view, and consider the molecules of our nerve-cells as vibrating in a given manner according to the dynamic influence of their chemical surroundings or environment, we shall at once understand that a slight change in the latter might suffice to alter the mode of vibration, or, in other words, produce a different and apparently antagonistic physiological effect.

Action
and re-
action.

In estimating the physiological effect of any drug, both its action and reaction must naturally be taken into account, and since all drugs act by influencing

the rate and degree of oxidation, it is very evident that the amount of oxygen contained in them in proportion to the other elements, and perhaps especially to nitrogen, is of considerable importance. Indeed, the degree of oxidation of all vegetal products is probably one of the chief factors, though, of course, not the only one, in the determination of their chemical characteristics and physiological effects. Bitters and alkaloids in general may be said to produce in the first instance an astringent or constricting effect on the tissues with which they come in contact. Whether or not this result leads to a diminution, or to an increase, of oxidation depends on the condition of the tissues previously in respect to contraction or relaxation, and this naturally applies in the case of strychnine; but it is certainly true that the more any tissue is contracted, the less easily does oxidation in it take place. The action, however, of drugs which produce constriction of the tissues, and so diminish oxidation, is probably always followed by a reaction in the opposite direction, which varies very considerably in different cases, depending partly on the chemical composition of the alkaloid or bitter employed, and partly on the physiological condition of the person taking it. There are, indeed, certain general truths connected with the action of all drugs which one may express as follows :

All drugs influence the rate and intensity of the oxidation of the tissues both by their action and by their reaction.

Every increase in the amount of oxygen in a tissue leads to, or is accompanied by, expansion, whilst every decrease in the amount of oxygen in a tissue leads to contraction. The presence of carbonic acid in the tissues is also probably a stimulus to contraction.

The mode of vibration of the molecules of nerve-cells depends on the manner, degree, and frequency with which the variations in the state of oxidation of the tissues are produced. Excessive oxidation causes relaxation.

The period and degree of action and reaction of all drugs varies, firstly, according to their composition, and, secondly, according to the habitual mode of vibration of the molecules in the nerve-cells of the individual.

The
apparent
effect of
drugs on
the gray
matter.

If you scrape some of the gray matter from the brain of an animal which has been recently killed, and tease one portion of it on a glass slab or small dish with water, another with a weak solution of acetic acid, and a third with a fairly strong solution of strychnine, you will notice that the first of these is more milky in appearance than the other two; and whilst the cells in the watery specimen show a tendency to dissolve and become fused, those in the strychnine and acetic acid are inclined, if anything, to contract and appear curdy or caked. Under the microscope the three specimens give corresponding results, a strychnine preparation being especially remarkable for the sharpness of the outlines of the nerve-cells and of their granular contents. If, again,

you leave a brain for some weeks in strong alcohol, it becomes, as is very well known, hard and compact. The meaning of this is doubtless that a general contraction of the molecules, of which its substance is composed, has taken place; they have, that is to say, grouped themselves in closer order. The results thus obtained indicate to some extent the physiological action of the various substances mentioned on the nerve-cells in a living animal. If we adopt the modern view that ether permeates all matter, it is evident that the molecules of nerve-cells must be surrounded by it. When, therefore, they vibrate, as in nervous action they probably do, there is, as it were, a link between them and the molecules of any foreign substance—such, for instance, as strychnine in the blood—and the movements of the nervous molecules would, under these circumstances, naturally tend to become influenced and modified by their surroundings; and this, it may be supposed, would occur whether or not the strychnine molecules were taking part in the chemical action going on in the blood or lymph around the nerve-cells.

If we suppose that the molecules of nerve-cells vibrate in agreement with the degree of oxidation and the degree of contraction of the tissues to which they correspond, it is evident that any change in the latter must be followed, or accompanied by, a modification of the vibrations of the former; therefore, when the system is stimulated to increased oxidation these vibrations must be affected thereby. But as the

The
nature of
physio-
logical
reaction.

effect of the stimulus decreases, the molecules of the nerve-cells conforming to the change in the conditions of their environment take upon themselves an altered form of vibration—one, that is to say, which corresponds to a state of diminishing oxidation. If the stimulus to oxidation were abnormal or excessive, the amount of carbonic acid produced would naturally be so also, and the presence of a larger quantity of this gas in the blood than usual—larger, perhaps, than the circulatory and respiratory systems could readily cope with—would tend to modify the vibrations of the molecules of the nerve-cells. An excess of carbonic acid in the blood, even when the supply of oxygen is made ample by artificial means, produces, it is said, a narcotic effect, acting not only on the respiratory centre, but on the central nervous system and brain.* Carbonic acid also stimulates the respiratory muscles and causes deeper breathing, and if it act in the same manner on the tissue of the lungs and pulmonary vessels, either directly or indirectly, it would also produce contraction, it would seem, in these parts, and so diminish the aeration of the blood. If we look upon all contraction as the passage from a higher to a lower state of oxidation, it is easy to see how carbonic acid, which represents the latter, should cause increased muscular action so long as the muscular tissue is fairly well supplied with oxygen.

There are many drugs, including probably the

* Foster, *loc. cit.*, p. 601.

majority of bitters, alkaloids, and narcotics, the primary effect of which is to diminish and not to increase oxidation; and it is clear that when under their influence a variation in the vibrations of the nerve-cells takes place the change or reaction would not be in the direction of diminished oxidation and greater contractility, but of increased oxidation and greater expansion, going in some cases so far as extreme laxness. It therefore becomes a question of some moment whether the action and reaction of all drugs should not be considered primarily from the double point of view of their effect on the degree of contraction and of oxidation of the tissues. In so doing, however, it is essential to remember that the reaction of a drug may be beneficial or the reverse, but that in general it is more permanent and lasting than the primary action. This is a fact which is the more likely to be overlooked, since one is always inclined to ascribe improvement after medicinal treatment, especially in the case of many tonics, to the action of the drug administered, whereas in reality it is frequently due to the reaction of the system after the drug has ceased to act. Nor is this, as at first sight might appear, a matter of slight importance, for it is evident that in the case of a patient, the vibrations of whose nerve-cells tend habitually to the side of excessive contraction and diminished oxidation, the application of a tonic, which by reaction produces these very effects, could only ultimately increase the evil, whereas in cases of an opposite nature it might

lead to gratifying results. Diminished oxidation, however, though frequently due to excessive contraction of the nerve-cells, may also be caused by the opposite tendency, especially when this laxness is of such a degree as to produce considerable decrease in blood-pressure. There are cases in which the nerve-cells vibrate sometimes in a too contracted state, and sometimes in a condition of too great expansion. When the hyper-contracted state is habitual, it will by degrees lead to diminished oxidation to such an extent as to interfere with the due nutrition of the tissues and thus indirectly bring about dilatation of the arteries by weakening the muscular coats. In all this, the habitual mode of vibration of the molecules of the nerve-cells is the factor, to obtain control of which should be the aim of treatment. Apart, however, from the use of drugs, reaction must be regarded as a normal and natural event, for well-nigh all parts of the human organism are subject to variations of oxidation and of contraction, which are the primary factors in all physiological action.

Some
factors in
metabo-
lism.

The tissues of every living organism may be said to consist, finally, like other substances, of molecules and atoms; whilst surrounding these, and permeating the whole is, we have reason to suppose, the ether. In the manifold processes of oxidation which occur both during functional activity and in a state of repose, the molecules break down and are built up, and this fact implies the existence of certain forces by which these events are caused and controlled.

The blood carries the same raw materials to every region of the body. By what means is the selection in the various tissues made? and what are the conditions which determine the nature of the chemical combinations whereby the renewal of them is assured? Complicated in the highest degree though the processes of metabolism taken separately undoubtedly are, the main factors in them are, on the contrary, probably very limited. Amongst them it is necessary to concentrate one's attention in the first place on the tissues, the nervous system, and the ether.

When new molecules are formed in any tissue they resemble the old in their chemical composition. Though the various substances which go to form the tissues are of a complex nature, and are elaborated or prepared in other regions than those for which they are finally destined—though, indeed, in some instances, as in that of lecithin, bodies are found in many parts of the organism in that form which they retain when built up into tissue—yet, speaking generally, the ultimate absorption of nutritive matter is a process, not merely of physical attraction, but essentially of chemical action also. The tissues constitute the workshop in which new tissue is manufactured, and they must therefore be regarded in a great measure as the moulding agency. But if the tissues are to exercise an influence of this kind they must be active—they must, that is to say, transmit force either directly or through some medium to the materials in the lymph which bathes them. Now, if we suppose

The selection of materials by the tissues.

the ether surrounding the molecules to constitute a medium capable of transmitting minute vibrations exactly corresponding to the chemical composition of each class of molecules, we shall be able to understand—in part at least—how it is that the loose materials in the lymph always group themselves in each region of the body in the same proportions, so that the continuity of the tissues is insured. To put the matter briefly, environment determines the nature of the new product.

The degree of oxidation going on chiefly determines the nature of the compounds.

But amongst the individual factors in this environment there is one, namely oxygen, which plays the foremost part. Oxidation is, as we well know, the pivot on which all metabolism turns, and a given degree of oxidation of the tissues is one of the conditions essential to the formation of new tissue. Chemical bodies containing a large proportion of oxygen must naturally be formed under conditions of relatively higher or intense oxidation. The intensity of oxidation is probably dependent partly on vibratory influences, and partly on the presence of a given amount of oxygen.

If we regard the ether as a medium permeating the whole body, and everywhere surrounding the molecules of which it is composed, we may suppose that any movement whatever would throw it to a greater or less extent into a state of vibration, and with it the molecules also, so that they would react upon the ether, and through it, as we have said, upon the materials about to be formed into new

tissue. It is evident, therefore, that all forms of movement, but especially those which are continuous, may, and probably do, play a very important part in the processes of metabolism. The influence of the respiratory movements is especially worthy of consideration in this respect. These produce a series of variations of blood-pressure which are probably felt throughout the whole organism, and can scarcely fail to influence the mode of oxidation of the tissues. When the skull of a living animal is removed, the brain may be seen to rise up during expiration and to sink during inspiration.* Expiration is held to hinder and inspiration to facilitate the return of blood from the brain, and it is evident that this applies not only to the blood returning from that organ, but also to that coming from other parts of the body. At the same time, whilst venous pressure is diminished during inspiration to the point of becoming negative, arterial pressure is, on the contrary, increased, though not in a manner which is exactly synchronous with the inspiratory movement.† The former, indeed, follows close upon the latter, and attains its maximum only at the beginning of the expiratory movement. These variations of pressure in the thorax and in the vascular system in general must lead to corresponding variations in the degree of oxidation in the tissues; for, as the arterial blood-pressure rises, so must the pressure of the lymph and of the oxygen it may for the moment contain be

* Foster, *loc. cit.*, p. 613.

† *Ibid.*, p. 614.

increased. But this increase in oxygen pressure is accompanied by a decrease in carbonic-acid pressure, due to the negative pressure in the veins. Metabolism must therefore possess a rhythmical character; moreover, it is not improbable that as the blood-pressure rises and falls with the respiratory movements, the tissues also expand and contract. Thus, when arterial pressure has attained its maximum at the beginning of expiration it seems likely that the transfer of oxygen to the tissue, which may then be supposed to take place, is accompanied by a certain degree of expansion. Indeed, unless we imagine some such movement to occur in the nerve-cells, it is difficult to conceive how the molecular and chemical action going on in them can govern the metabolic processes taking place in the tissues. However this may be, it will be seen that, so long as respiration continues, molecular movements and ethereal vibration never cease in the nervous system and tissues generally, so that even in the deepest sleep there are forces at work which determine the mode in which the building up of raw material into new molecules shall take place. But though the respiratory movements and the influence of nervous vibration upon the tissues may be regarded as contributory causes in the formation of new molecules, yet the facts that metabolism will go on in the stomach after most of the nerves to that organ have been cut, and that growth in the case of the hair and nails will continue after death show that chemical action, the ether and

molecular environment of a given kind are alone essential. These are also the chief factors in vegetal growth in which ethereal motion in the form of light plays so important a part.

Of all elements oxygen is admittedly the most negative, or, in other words, the most attractive ; and although these terms are usually applied to it in an electrical sense, yet all that we know of its behaviour chemically justifies to a great extent an extension of their meaning so as to cover this second form of action. Electrical and chemical phenomena, especially in living matter, are so intimately connected that it would probably be impossible to draw a clear dividing line between them. When oxygen passes from the capillary into the lymph surrounding the tissues, it tends, we may suppose, by reason of its attractive power, to group the other elements round it so as to form new molecules, which, if the vibratory conditions be favourable—that is to say, not excessive, and yet sufficient—will then take place. In a similar way, when the vibratory conditions become either too weak or excessive, the oxygen breaks away from its surroundings, forming new compounds. If the state of oxidation of muscular tissue be variable, as we have reason to suppose it is, this extreme negativity of oxygen may be a factor of primary importance in contraction ; for when the diffusive or attractive influence of oxygen is diminished, it would seem likely that the elements in those bodies which remain should possess a greater power of attraction for one another.

Muscular contraction is a process of deoxidation.

When a muscle contracts in rigor mortis it will give off a considerable amount of carbonic acid. It will do this even if placed in a vacuum, after it has been shown by means of a mercurial air-pump to contain no free oxygen.* It is clear, therefore, that the oxygen of the carbonic acid was held in the muscular tissue either in that form or in some more complex body. Since, however, carbonic acid is one of the chief products of muscular contraction, not only in rigor mortis but in the normal state also, there seems to be some ground for supposing the muscular contraction to be essentially a process depending on a diminution of the supply of oxygen in the tissue. The more perfect the state of oxidation before the contraction takes place, the greater the diminution would naturally be under the influence of a sufficient stimulus. Thus, though perfect oxidation is essential to muscular action, the actual cause of the contraction lies probably, as remarked, in a diminution of the state of oxidation of the tissue taken as a whole. There appear, however, to be reasons for believing muscular tissue to be of a complex nature, and it is likely that one or two only of the various bodies which compose it break up in the contraction, whilst the molecules of the other bodies coming under the influence, so to speak, of a wave of diminished oxidation, group themselves in the peculiar manner which constitutes muscular contraction. The production of heat during the contraction can only be attributed in a general

* Foster, *loc. cit.*, p. 100.

way to this movement of deoxidation, since it is not known whether the carbonic acid is produced at the moment, or, having been previously formed, is merely liberated. It is when we look at muscular contraction from the point of view of the tissue which remains after the oxygen has been expelled in the form of carbonic acid or otherwise that it will appear to us to be essentially a process of diminishing oxidation.

Although functional exercise is rightly regarded as one of the conditions most essential to growth and development, there is probably no reason for supposing that both katabolism and anabolism take place to an equal extent either during action or during repose. The recuperative influence of sleep and the lassitude and weakness which is caused by a lack of it seem to point to the conclusion that the anabolic factors predominate in this state. As to the general character of sleep there can be very little doubt. The decrease in the amount of carbonic acid produced shows that it is essentially a period of diminished oxidation, and this condition is, it would seem, the most favourable for the building up, if not of all the tissues in the body, yet at any rate of some of the most essential, and especially, one may suppose, of nervous matter, which in its chemical composition contains relatively so small an amount of oxygen. Absolute rest of body and mind has been recognised to be one of the most efficient methods of restoring nervous power. Amongst farmers it has long been

Condi-
tions most
favour-
able to
anabolism.

a practice to keep cattle which they wish to fatten in dark stalls, and whatever drawbacks it may have from a sanitary point of view, there is little doubt that by diminishing the supply of light, and thereby limiting the degree of oxidation, a more rapid gain in weight may be obtained. Although the rapidity of growth in children and young animals is doubtless due to several factors, one of the most important is undoubtedly the amount of sleep which they get. In the first few weeks of its life an infant will often sleep eighteen or twenty hours out of the twenty-four, and the longer it sleeps the better it will thrive. It is said that during sleep the brain is anæmic, and the constriction of the pupil of the eye suggests contraction of the cerebral bloodvessels. However this may be, the diminution of respiratory movements, the slowing of the pulse, the lessened production of urea, and the lowered temperature, all indicate decreased metabolism; and yet such metabolism as still takes place is, we may suppose, anabolic in its character rather than katabolic.

The contractility of nerve-cells.

During expiration, as already remarked, the brain as a whole rises and the blood-pressure sinks; whilst during inspiration the reverse happens, the brain sinking and the arterial blood-pressure rising. These variations, it was said, cannot but exercise a certain influence on the nerve-cells, and we may expect them to be accompanied by appreciable changes in the state of oxidation and of contraction. The question of the contractility of the nerve-cell is, however, one of such

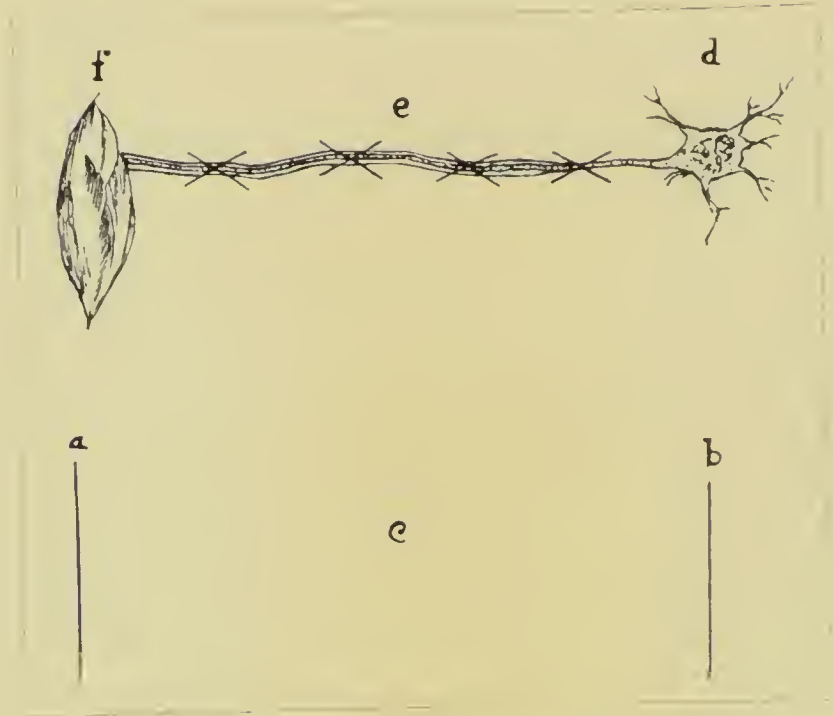
general interest that it may be worth while to consider certain other aspects of it. The power of attracting and repelling is, as everyone is aware, one of the primordial properties of matter, and is frequently brought into play by the variations of chemical environment which in any given case may happen to obtain. Since in animal tissues oxidation and de-oxidation are the common basis of all movement, the vibrations of nerve-cells may without doubt be attributed to the same general cause, and if this be so, then variations in the mode of vibration must evidently depend on the degree of oxidation. But it is certainly very difficult to imagine any variations of movement and of position amongst the molecules of nerve-cells which would better correspond to changes in the degree of oxidation than would variations of contraction and expansion. If the nerve-cell itself were contracted, or if within it the molecules were grouped more closely together—it may be in tiny collections such as would give it the granular appearance we know it to possess—the molecules would, one might suppose, react on one another with greater rapidity, and if the grouping were not too close, with greater intensity. Such a grouping would correspond to a state of diminished oxidation, for many of those drugs which produce a diminution of oxidation cause constriction or drawing together of the tissues with which they come in contact, and within certain limits an increase in the intensity of nervous vibration. The nature of glandular secretion during very violent

attacks of asthma, when the supply of oxygen is to a great extent cut off, is of such a kind as to suggest very rapid production and incomplete oxidation. Whether this result is a direct or an indirect one really matters little, for it is evident that both in the gland and in the nerve-cell a diminution of oxidation causes excessive activity or movement. Contractility, moreover, is a property of protoplasm in general, and there is the less reason to make an exception of nervous matter since the axis cylinder of a nerve-fibre resembles chemically in its general features muscular tissue. Experiment also confirms the view that the nerve-cell, if it behave as ordinary protoplasm, contracts and expands in accordance with the changes in its chemical environment, and in this respect the following passage is of great interest:

‘Referring again to Ehrlich’s observation, we can see that if anæsthetics and hypnotics cause contraction of the protoplasm in the cells of nervous centres, they will thus lessen oxidation and tend to diminish functional activity. Such a contraction might be caused not only by alkaloids like morphine, but by a mere change in the reaction of the cell or of the fluid surrounding it. When free cells, such as amœbæ or infusoria, are treated with very weak acid they contract, and with weak alkali they swell up. It therefore seems probable that mere diminution of alkalinity by the products of tissue-waste may tend to lessen oxidation in the brain-cells by contracting the proto-



DIAGRAM TO ILLUSTRATE THE PART WHICH THE
ETHER PLAYS IN NERVOUS ACTION.



a, b, Marconi's wireless telegraph poles ; *c*, the ether in a state of tension ; *d*, a nerve-cell permeated by the ether, which undergoes variations of tension as the molecules of the cell move hither and thither as a result of oxidation in part of the cell ; *e*, a nerve fibre ; $\times \times \times$, a stratum of ether, variations in the tension of which, caused by molecular movements in the fibre, give rise to the current of action ; *f*, a muscle also permeated by the ether, variations in the tension of which help to convey the nerve impulse to the molecules of the tissue.

To face p. 45.

plasm at the same time that the changed reaction lessens their affinity for oxygen.'*

Since every increase of blood-pressure must per- Variations
force mean an increase of oxygen pressure round the tension of
nerve-cell, we may suppose that with every inspira- the ether
tion fresh molecules of oxygen are squeezed into its as the
substance, and passing amongst the granules of which cause of
it is composed, oxidize, or become allied with some the
of the elements present. Whilst at each increase in current of
the supply of oxygen to the nerve-cell some of the action in a
molecules of the latter break up and are got rid of, nerve-
the remaining ones may be supposed to come under fibre.
the influence of a vibratory wave, the character of
which is determined by the degree of oxidation. This
wave is transmitted from the cell to the periphery in
the case of an efferent nerve, probably by molecular
movement in the nerve-fibre. But at the same time
that this molecular transmission takes place a second
event occurs: the molecules of the nerve-cell are
everywhere surrounded by ether, and along the
nerve-fibre to the periphery there is also a stratum
of ether. The movement of the molecules is there-
fore communicated to this other medium in which
certain variations of tension make themselves felt.
These variations are what is termed 'the current of
action' or 'negative variation.'

In addition to variations of blood-pressure, the The influ-
degree of oxidation is influenced by other factors, as, ence of
functional
activity on
metabo-
lism.

* Sir T. Lauder Brunton, Introduction to 'Modern Therapeutics,' pp. 112, 113.

for instance, by the amount of oxygen in the blood, by the presence or absence of chemical substances conducive or otherwise to oxidation, and by the degree of vibratory activity in the nerve-cell. Both the degree of oxidation and of movement in the protoplasm of the nerve-cell are naturally greater during functional activity than in a state of repose, and less during sleep; and if in the first of these conditions a note of increased or diminished oxidation is repeatedly struck which considerably exceeds the normal limit, the molecular movements of the cell will, little by little, become exaggerated, not only when the cell is active, but also, though to a slighter extent, when it is, relatively speaking, at rest, and thereby the nature of the metabolism may be altered.

The influence of contraction and expansion on oxidation.

If, as there appears to be reason to believe, contraction and expansion constitute a most essential part of nervous action, the nervous system may be likened to a pendulum, swinging now to the side of increased oxidation, and now to that of decreased oxidation. Yet in order that the simile may fully represent not only normal action, but pathological action also, it is necessary to suppose that the point of attachment or pivot on which the pendulum swings may be shifted to a greater or less extent towards increased oxidation and greater expansion, both of which then predominate, or towards decreased oxidation and greater contraction, which in like manner become excessive. The rhythmic movements continue as before, in accordance with the variations of blood-

pressure; but as the conditions under which they have been going on are such as lead chiefly to contraction, or chiefly to expansion, so does their general character incline more in this or that direction. What those conditions are has already been described in dealing with physiological reaction. Irrespective of the influence of respiratory movements on blood-pressure, vaso-motor changes, when excessive and frequent, are probably one of the chief causes of an ill-balanced state of metabolism, although the anatomical relations of the vaso-motor centre to the rest of the nervous system, and especially to the brain, are but little known.

What is the nature of the force transmitted by a nerve-fibre? Is it molecular? is it chemical or atomic? is it electrical? There are many who deny that the nerve impulse is of an electrical order; but the statements on this point are not absolutely conclusive, although in some measure doubtless true. The facts on which they rest are briefly as follows: The velocity of an electrical current in a nerve-trunk is far greater than that of a nerve impulse passing along the same fibres. A nervous impulse is not transmissible by an electric conductor—as, for instance, by a copper wire. If you ligature a nerve, it will no longer transmit nervous impulses, but will still act as a conducting medium to an electrical current. A crushed motor fibre which has lost its functional power will generate electricity for a time.

The nature
of the
nervous
impulse.

With respect to the arrest of a nerve impulse by a

ligature, it may be argued that the difference in electrical potential between one part of the body and another being always very slight—much less indeed than that which exists between the two plates of a battery—the interruption of the nerve current might be more easily effected than that of the electrical current. The former is also very much the weaker of the two, and the rate at which it travels suggests either that it has to overcome a certain degree of resistance, due possibly to the slight difference of electrical potential already mentioned, or that it is generated anew all along the fibre. When a nerve impulse takes place, it is accompanied by an electrical change passing along the nerve-fibre. This change, the negative variation or current of action, as it is called, is evidently bound up with certain changes in the nerve-cell, the nerve-fibre, and its peripheral ending. Yet no development of heat nor signs of chemical action have hitherto been detected in a nerve-fibre after action, so that either they are so minute as to escape detection, or the only change is a molecular one, accompanied by an electrical movement or variation. What, then, is the nature of the nervous impulse?

Electrical
vibration
is always
connected
with
chemical
or with
molecular
vibration.

To meet all the necessities of the case, it seems as though we must look on it as a compound in which the elements are chemical, molecular, and electrical. Really, if we reflect, we shall probably find it impossible to exclude any one of the three. From the electrical variation, or current of action, of which

we have conclusive evidence, we may certainly infer either chemical or molecular action. Has, indeed, we may ask, an electrical current ever been known to exist which has not originated in, been accompanied by, or given rise to, chemical—that is to say, atomic—action or to molecular vibration? When the lightning flashes from the clouds on a midsummer's day, are not the molecules of water and air vibrating intensely, owing to the heat and friction to which they are subjected? When a very powerful current of electricity is made to pass along a thin copper wire, will it not cause the molecules to vibrate until they glow with red-hot intensity? May we not believe, therefore, The three elements. that the presence of electrical action in a nerve fibre indicates that molecular vibration is taking place? The molecular element seems the more essential, since without it it would be very difficult to explain all the varieties of sensation, especially those forms of it in which no end organ participates and, as far as the periphery is concerned, little or no chemical action is observable. In this category must be classed many effects due to the tactile sense and others belonging to the muscular sense. Some effects, again, such as the lighter ones of the tactile kind, as, for instance, tickling with a hair, seem so insignificant as almost to suggest an electrical origin, or, at least, that electrical variation plays an important part in them. In all such cases, if we exclude the latter, molecular transmission is the only explanation on which we can fall back; and it seems justifiable,

therefore, to regard it as an essential factor in nervous action.

The chemical element is also essential. Firstly, because sensation is impossible without oxidation in the nerve centres; and, secondly, because certain forms of sensation are directly due to chemical action at the periphery. Lastly, the electrical element, accompanying as it does the impulse step by step, must, one would think, for other reasons than that already given, play some part in its transmission. It seems contrary to all reason to suppose that an active force, such as electricity, can be merely passive and exert no influence on such loose and mutable compounds as those of living tissue. We know that when passed through the tissues from a battery it induces metabolism, and we may therefore infer that when generated in the body it contributes to bring about chemical action, if not in the nerve fibre, at least in the nerve-cell. Indeed, if we adopt the modern view of physicists, that the ether permeates all matter, if we look upon it as being in a state of tension, and if we consider electricity to be a movement in it due to variations in that state, then it will seem impossible that electrical action should take place without reacting on the molecules of the region in which it occurs. We may, indeed, with this torch in our hands, penetrate into the very arcana of nervous action; for if we suppose a certain number of the molecules of a nerve-cell to be in the act of oxidizing, and to produce thereby variations in the tension of

the ether permeating the cell, we can understand how it happens that the other molecules, for the oxidation of which the supply of oxygen is insufficient, nevertheless become in a certain measure active, and vibrate. Further, if again we suppose that light consists of waves of force transmitted through the ether, we shall see that the very origin of what one may term our chief sense, if not electrical, is very closely allied to electricity. We cannot shut our eyes to the accumulating evidence of the electrical nature of living tissue. Cutaneous, glandular, muscular, and nerve currents are known to exist, and are, indeed, a constant phenomenon in the functional activity of the corresponding parts. The heart has two electrical areas: there are retinal currents; there are currents of injury. To produce a current it is sufficient, as Galvani has shown, to make a muscle preparation with a portion of the nerve attached, to raise the latter, and allow it to fall suddenly on another muscle preparation, or even on the same muscle, so that it may unite as far as possible injured and uninjured parts. In this case the current is generated and transmitted through muscle and nerve alone without the aid of electrodes or wire. Thus, it will be seen that variation of potential, or, as one might call it, of ethereal tension coupled with molecular agitation, will, under certain conditions, produce muscular contraction. These facts, to which others might be added, seem to support the view that electricity in living tissue is by no means an inert

Electrical
pheno-
mena.

force, but one which contributes in a very real and essential manner to the development of every kind of physiological action. The passage of an electrical current along a nerve fibre usually produces, it is true, no specific form of sensation, whilst even the electrification of parts of the cerebral cortex frequently fails to yield any result of a functional order. If, therefore, electricity, as it seems probable, does play an essential part in nervous action, it can only be, one would think, because the ether (regarding electricity as ether in motion) takes upon itself, for a certain distance, at any rate, the character of the molecular or chemical action, which is the primary origin of the nervous impulse, subsequent modifications always bearing a certain relation to it.

Many other curious phenomena of an electrical order pass daily before our eyes. Women's hair, when combed, will often stand off from the head, as though momentarily stiffened, and will crackle when the comb passes through it. The cat which rubs itself caressingly against your leg probably finds its enjoyment in a flow of electricity, by which the tension of the spinal centres is relieved and metabolism stimulated. Some authors, it is said, cannot work successfully unless they have a cat about them, which from time to time they stroke. That part of massage which is termed *effleurage*—that is to say, the light rubbing of the skin—gives rise, especially when applied to the back and spinal column, to a drowsy relaxation precisely similar to that usually produced by electrical

treatment in a bath. Even the passing of the hand over the tired brow or through the hair causes relief, and the person operating will sometimes, if of a sensitive nature, feel a tingling in his or her finger-tips. Some persons are sent to sleep by these and similar methods.

It is a fact, not without interest in its bearing on the part played by electricity in the animal economy, that the more a person is electrified, the more disposed does his or her nervous system become to take upon itself the character of the conditions under which it is functioning. Thus, electrification of the body under relaxing conditions will intensify their effect, whilst electrification under the influence of a drug will very greatly intensify both its action and reaction. The nature of the result depends on other factors also—on the kind of current, on its strength, and on the parts to which it is applied. When the spinal cord and cerebellum are electrified, the effect is more pronounced than if the electrification be restricted to the limbs and periphery in general. That electricity should intensify any influence to which the body is subjected is but natural, for its action is undoubtedly to throw the molecules and atoms of the tissues into a state of intense vibration, and matter in motion is always more easily affected than when quiescent. Take, for instance, the piece of iron which the blacksmith fashions for a horseshoe, and which he can mould to his fancy when the fire has made its molecules vibrate.

Electricity intensifies the effect of the conditions under which it is administered.

Electricity
as an
almost
neutral
agency.

In the physiological effects to which we have alluded electricity plays a, comparatively speaking, neutral part, that chiefly of an intermediary. This, moreover, is entirely in accordance with the theory already advanced, that electricity is a mode of motion of the ether; that the latter acts as a go-between transmitting force, the kind of which depends on the nature of the various forms of matter from which it proceeds; and, lastly, that electrical potential is due partly to the tension natural to the ether, and partly to the action of excited groups of molecules and atoms upon the ether, which, becoming imbued with their special vibratory character, convey it to other atoms and molecules, the attractive and repulsive power of one electrified substance for another being thus evolved.

The effects
of high
altitudes.

The nature of the air we breathe is universally recognised as exercising a most marked influence on the nutrition of the body, and from time to time during the past century the subject has been approached from the point of view of the effect produced by residence at various altitudes. After De Saussure, it was handled with great ability by that much-abused French physiologist, Paul Bert; and quite recently an important work* by Mosso has appeared, whose opinions in regard to some essential points are at variance with those of the latter.

According to Flammarion, the pressure of the atmosphere at 2,600 metres above sea-level is diminished

* 'Der Mensch auf den Hochalpen.'

by one-quarter, at 5,500 metres by one-half, and at 9,500 metres by three-quarters.* For every 1,000 feet of ascent the barometric pressure falls, roughly speaking, 1 inch, although in reality the fall is slightly greater at low levels than at high ones.

The general effects of ascending suddenly to a Mountain sickness. height at which mountain sickness supervenes in its acute form are loss of bodily strength, helplessness, a feeling of sickness, vomiting, a bluish coloration of the skin, tingling of the ears, disturbed vision, breathlessness, palpitation, and fainting.† It is related that when cats are taken up into the mountains above a certain height they succumb after violent epileptic attacks. On human beings, however, the effects of high altitudes are very variable. The monks living at the monastery on Mount St. Bernard, which is 8,117 feet above the sea, become asthmatic; on the other hand, Potosi,‡ in America, is 3,960 metres above sea-level, and at one time had a population of 160,000; whilst Quito, Bogota, and Micuipampa are all above a height of 8,500 feet. On the Ibi Gamin, in Thibet, the brothers Schlaginweit attained a height of 22,230 feet without any other ill-effect than great fatigue.§

There are few problems even in physiology which present greater difficulties than that of the effects of a rise in altitude, the discussion of which has yielded

* Flammarion, 'L'Atmosphère,' p. 72.

† Mosso, *loc. cit.*, p. 229.

‡ *Ibid.*, p. 189.

§ *Ibid.*, p. 230.

The chief points.

such meagre results ; nor is it intended here to do more than draw attention to some of its more salient aspects. The degree of atmospheric pressure, the amount of oxygen in the air and in the blood, the proportion of carbonic acid in the blood, the effect of electrical or ethereal conditions, and the mode of functioning of the nervous centres in the race or in the individual—these are points which appear to merit consideration.

The importance of the nervous factor.

That animal life may exist in a state of normal health and activity at very great heights is clearly shown in the case of the condor, which, according to Humboldt, flies as high as 21,834 feet ; whilst eagles and vultures have even been observed by the Schlagin-weits at a height of 23,000 feet above the sea.* These facts considered in conjunction with the inability of cats to withstand a height of only about 13,000 feet point to the conclusion that the essential factor is neither absolute atmospheric pressure nor the absolute amount of oxygen in the air, but the readiness of the nerve centres governing metabolism to adapt themselves to conditions more or less removed from those to which the race or the individual has been habitually subjected. In other words, a cat's blood exposed to the air at a given level above the sea would probably oxidize as fully and as rapidly as that of an eagle, yet the transmission of oxygen from the blood to the tissues and the formation of carbonic acid does not take place in a regular manner in animals belonging

* Mosso, *loc. cit.*, pp. 21, 22.

to lower levels when transported suddenly to heights above 8,000 to 9,000 feet. Mosso mentions, on the authority of Hüfner, that hæmoglobin artificially prepared would absorb a normal amount of oxygen even on the top of the Himalayas.* Analyses of dogs' blood by Geppert and Fraenkel showed that the amount of oxygen in it was not diminished until the atmospheric pressure had fallen to 410 mm.,† although mountain sickness is often observed in a violent form at a pressure of 500 mm., the equivalent of a height of 3,300 metres. Hüfner even goes so far as to say that mountain sickness cannot be attributed to a chemical or physical change in the blood until you reach a height of 9,000 feet.

The analyses just referred to demonstrated another important fact, to which Paul Bert had also drawn attention, viz., that as the air becomes more and more rarefied, the carbonic acid in the blood diminishes more rapidly than the oxygen, the proportion being 1·63 of the former to 1·0 of the latter. Mosso, who has performed many experiments and collected a good deal of evidence all tending to support this statement, is inclined to regard the diminution of carbonic acid in the blood as the main or most direct cause of mountain sickness.‡ Doubtless the amount of carbonic acid in the blood exercises a considerable influence on the respiratory centre, and it may be on the nervous system

The relative diminution of carbonic acid and oxygen in the blood.

* Mosso, *loc. cit.*, p. 400.

† *Ibid.*, p. 401.

‡ *Ibid.*

as a whole; indeed, it has been stated that it affects other parts of the nervous system, and especially the brain, more markedly than the respiratory centre.* The bare fact that arterial blood contains twice as much carbonic acid as oxygen is enough to convince one that it is an important factor in metabolism; and when one reflects that with every inspiration the oxygen pressure around the nerve-cells is increased, and that with every inspiration also the carbonic acid pressure round the nerve-cells is diminished by the sucking action of that movement on the great veins, surely this conviction must be still further strengthened.

All metabolism may be said to take place, as we have seen in the case of muscular contraction, between certain limits of oxidation and of deoxidation, or, if the expression be permitted, carbonic acidification. It is impossible, in view of the composition of arterial blood, to regard carbonic acid merely as a waste product without influence on the nervous system, for the proper functioning of which, indeed, a certain balance between the two gases is probably essential.

The effect of variations in the relative accounts of these gases.

An abrupt but continued alteration in the proportions in which they figure in the blood, if excessive, results in a disorganization of the nervous system. The effect of carbonic acid on the nervous system is naturally very variable, depending as it does not only on the degree in which it is present, but on

* Foster, *loc. cit.*, p. 601.

the degree of oxidation of the tissues. A slight increase of carbonic acid stimulates contraction whenever the tissues are sufficiently oxidized; and similarly a slight increase in the amount of oxygen in the blood, if absorbed by the tissues, stimulates contraction whenever they previously have been insufficiently oxidized. A great proportional excess of either gas in the blood tends, on the contrary, to diminish metabolism, and in some cases brings about spasmodic action of the nerve centres. The increase in the amount of carbonic acid which takes place during violent exercise makes its influence felt by rendering muscular contraction after a while more feeble. Here, however, we have to consider not so much the temporary fluctuations as the long-continued changes due to differences of altitude. There is reason to suppose that, although the mode of functioning of the nerve-cells is at once modified by such changes, they still retain for some time something of the influence of the preceding conditions to which they were subjected. It is probably this compromise, so to speak, between the new and the old which is in a great measure the cause of improvement. This double action, indeed, suggests an explanation, and probably the only one, of the bracing effect of high altitudes; for when an individual goes from a low place to a high one, not only does his nervous system come under the influence of a relatively greater amount of oxygen in the blood, but it still remains for some time under the influence of the pre-existing

relatively ample, or it may have been excessive, amount of carbonic acid. When, however, at a given height the increase of oxygen in proportion to the carbonic acid in the blood exceeds a certain degree, this condition is by no means favourable to health in any save a few exceptional animals. This certainly seems to prove that the relative proportions of these gases in the blood affect the nervous system in a very fundamental manner.

Effects of
diminished
atmo-
spheric
pressure.

Although the inspiration of oxygen and the expiration of carbonic acid have been said to be influenced by physiological factors, it seems probable that the main, if not the most direct, cause of the relative diminution of carbonic acid in the blood is to be found in the decrease of atmospheric pressure. The general diffusibility of gases and liquids is, we may suppose, increased as you rise in altitude. Under these circumstances both oxygen and carbonic acid would find a more easy passage to and from the lungs, so that if we consider the events from this point of view there would be a gain in the amount of the former and a loss in respect to the latter. This, indeed, agrees with the results of analysis already mentioned. The gain in oxygen is, however, only relative, for the actual amount of that gas in the blood at a very great height decreases. Nor is this compensated by deeper breathing save in exceptional cases of exhaustion. The rule, indeed, seems to be rather that as you rise in height the respiratory movements become shallower, and this may be attributed both to

the greater ease with which the air enters the lungs, necessitating less respiratory effort, and also to the diminution in the amount of carbonic acid in the blood, whereby the natural stimulus to the respiratory centre is lessened.

There is a certain amount of evidence which tends to show that this intensity of chemical action is diminished as the atmospheric pressure falls. According to Dr. Saussure fire does not burn well on Mont Blanc,* and it is necessary to blow it continually in order to prevent it from going out. Although water boils at 84.03° it requires more time, and an amount which takes half an hour before reaching the boiling point upon the mountain would, with the same apparatus and the same amount of alcohol, attain that degree in twelve minutes at sea-level.† Tyndall found that stearin candles lasted longer on Mont Blanc than in the valleys below, and attributed this fact to the cold. But this conclusion was disproved by Benedicenti, who raised the temperature of the air surrounding the candles and oil-lamp which he used, and still noticed a marked decrease in the rate of consumption.‡ These examples tend to show that as you rise in height oxidation becomes less rapid. Curiously enough, however, an increase of the pressure of oxygen when carried beyond certain limits produces the same results. When the pressure of oxygen is very high, even phosphorus will not

Diminution of chemical intensity in high altitudes.

* Mosso, *loc. cit.*, p. 267.

† *Ibid.*

‡ *Ibid.*, p. 268.

ignite,* so that one would be inclined to regard the normal pressure at sea-level as the most favourable for chemical action. Alcohol when taken at a great height produces less effect than at sea-level, though this may be attributed partly to its more rapid elimination through the lungs and partly to other causes. Speaking in general, therefore, diminution of atmospheric pressure tends to restrict chemical action. To what extent, however, this would hold good in physiological processes it is probably impossible to say.

Observations on individuals in the Alps.

The view that oxidation is, in the absence of counteracting influences, diminished as one ascends to very high altitudes receives confirmation from the physiological results of many ascents and experiments. When Tyndall, at the top of Mont Blanc, sank down and fell asleep, Hirst woke him after a short while, exclaiming: 'You have given me a fright. I did not hear you breathe a single time, although I listened for it for some minutes.' Mosso, having taken respiratory tracings of two soldiers at Turin, which is 276 metres above sea-level, and at the Queen Margaret's hut, at a height of 4,560 metres, observed that although in one case the respiratory frequency was increased, yet in both the depth of respiratory movements was strikingly diminished. Experiments on other persons yielded like results, and were carried out so far as possible under similar conditions at the high and at the low level. One notable feature of breathing at great

* Foster, *loc. cit.*, p. 612.

heights is the oft-occurring and frequently regular pause between the inspiration and expiration, as though for a brief interval the need of fresh oxygen were not felt by the organism, and life were, so to speak, momentarily suspended. This is very clearly shown in respiratory tracings taken from two soldiers, Sarteur and Solferino. The case of Sarteur is of peculiar interest, since his respiratory frequency fell on one occasion to as low as eight per minute, although he was one of the strongest men of the party, and on being waked ate with appetite and felt well. These tracings were taken at the Queen Margaret's hut, and very remarkable is the difference in respiratory frequency, that of Sarteur being eleven and that of Solferino twenty-one per minute, although they were of the same age, almost the same size, had at the time eaten the same kind of food, and had walked the same distance. One sees from this example the importance of the personal or nervous factor.

The respiratory frequency of a dog, subjected by Mosso to the inhalation of air containing 16·7 per cent. of carbonic acid, rose from twelve per minute to as much as forty and forty-four.* Unfortunately, there is no evidence in this case of the depth of the respiratory movements; but if carbonic acid be, as is generally held to be the case, a stimulus to the respiratory centre, the more rapid elimination of it at high altitudes would naturally lead, as we have said, to shallower breathing, and this in turn would

Experiment to demonstrate the effect of carbonic acid on the respiratory movements.

* Mosso, *loc. cit.*, p. 416.

to some extent tend to reduce metabolism. Experiments in the pneumatic chamber show, as might be expected, that the amount of carbonic acid expired in the first half-hour is far greater than can be obtained afterwards, even though the pressure be very greatly diminished, so that the ultimate effect of greatly decreased pressure, when prolonged, is to lessen not only the actual amount of carbonic acid in the blood, but also the production of it, or in other words to retard metabolism.

The composition of the blood in high altitudes.

Many who have made a special study of the condition of the blood in high altitudes concur in the opinion that it contains, as a rule, a greater proportion of hæmoglobin, whilst some aver that the red corpuscles are also greatly increased in number. Although Mosso does not share these views, and expresses doubt, which is perhaps to a certain extent justifiable, as to the reliability of the experiments undertaken by the various observers, yet one can scarcely refuse to recognise the general probability of the facts asserted. If one be right in supposing that chemical action is retarded and rendered less intense as we rise in altitude above a certain height, that in other words the life stream is rendered less rapid, the sojourn in the system for a longer period of iron and other chemical substances becomes not only explicable but natural. Chlorophyll, one of the chief sources of iron for grass-eating animals, is probably the same at all levels, but the rate of excretion would depend on that of the vital processes in general.

If the intensity of these be diminished, a proportional accumulation of chemical matter might doubtless be looked for.

But if an increase of iron, of hæmoglobin, or of the red corpuscles be due, as seems likely, to diminished intensity of metabolism, it would disappear as soon as a return to a higher degree of tissue change took place; and it is generally recognised that the effects of residence at high altitudes are somewhat evanescent, more so in some cases, less in others, according to the special conditions of life and the idiosyncrasies of the individual. A relatively greater accumulation of oxygen-carrying or oxidizable material in the blood does not necessarily imply more rapid oxidation. The tissues, not the blood, are the chief seat of oxidation; and this is so partly because they are directly connected by nerve fibres with the nervous system which controls metabolism, and partly on account of their chemical composition. The connection of the blood with the nervous system is in this sense, so far as we know, only an indirect one. Trade may be said to be good when the demand is equal to the supply. So also in the present case, though a plentiful amount of oxygen in the blood may act as a slight stimulus to metabolism, yet the latter depends equally on such factors as exercise and the perfect functioning of the nervous system. The amount of oxygen in the blood, as also the amount of blood circulating in the nervous system and the blood-pressure, and the amount of carbonic acid in the blood, are all, however, important

factors in determining the nature and rate of metabolism, for these constitute the environment of the nerve-cell and in a great measure influence the character of its vibrations.

The influence of a place may be transmitted through the ether.

Although the beneficial effects of a slight rise in altitude and the opposite effects of a great rise may to a considerable extent be explained by referring them to the variations in the relative amounts of carbonic acid and oxygen in the blood, yet there are cases in which the solution of the problem must be sought in the influence of other factors. Residence on the top of a hill at a comparatively low level is frequently more bracing in its effects than a sojourn of the same duration in a hill-encircled valley far above it in height. Moreover, the beneficial influence which a situation of the former kind exerts on many constitutions is not of an evanescent character, and is often connected with a rise above sea-level so slight as to be quite inappreciable from the point of view of diminished atmospheric pressure. It has been suggested that such results are due to electrical influences. The degree of negative attraction of the earth varies, it is said, very considerably in different situations. Those which are free, open, and elevated as compared to the surrounding land are less negative than those which are low-lying, damp, and encircled by high hills. If we look upon electricity as being a mode of motion of the ether, and the latter as a great and universal medium whereby matter in one form or amount influences matter in another form or

amount, we shall probably see these facts in a new and clearer light. Obviously, the effect which the earth would transmit to us through the ether, whether considered chemically or physically, would be mainly one of inaction. Many people are influenced by sitting on the ground even on the hottest and driest days in summer under conditions which certainly do not suggest the transmission of cold. Surely in such cases we can explain the effect produced by supposing the active ether of our bodies, active because chemical action is always going on in it, to come under the sway or influence of the more quiescent ether which permeates the soil. A house situated on the top of a hill, especially if this latter be isolated, stands away and aloof from the ether of the earth to a far greater extent than one built in a valley or hollow.

Since there can be very little doubt that the variation in the relative amounts of oxygen and carbonic acid which are present in the blood exercises a considerable influence on the mode of functioning of the nervous system, it may be of interest to consider the results of massaging the body from this point of view. When the tissues are pressed and kneaded it is evident that a certain quantity of waste products must be squeezed out from them into the blood. Of these the most important, so far as the nervous system is concerned, is probably carbonic acid. The effect which this increase will produce will naturally depend to a great extent on the rapidity of the circulation, for the quicker this is the sooner will the carbonic acid be

Some
results of
massage.

eliminated. In old persons this is a matter of some importance, since they remain under the influence of this excess of carbonic acid for a longer time and to a greater extent than is the case with younger people. In many instances, and especially when there is a tendency to excessive vaso-motor action, a general contraction of the bloodvessels takes place, and is accompanied by pallor of the face. For a space also, owing to the effect of this excess of carbonic acid on the nervous system, metabolism receives a check. This, however, is more than compensated for ere long, for as this effect passes off, the vibrations of the nerve-cells, changing with the altered conditions, swing round, so to speak, to the side of increased oxidation and expansion. The degree of vaso-contraction and of vaso-expansion which occurs in any given instance will depend not only on the extent to which massage may have been carried, but also on the peculiarities of the individual with respect to vaso-motor action in general, and in almost any case they are likely to be somewhat excessive. It is natural—nay, one may say it is inevitable—that the increase of carbonic acid in the blood, due to the squeezing of the tissues, should affect the vaso-motor centre, for the relations of the vaso-motor nerves to the blood may be supposed to be of a closer nature than those of the other nerves. Massage differs essentially from ordinary exercise in the fact that the carbonic acid is heaped up without any corresponding effort being made to get rid of it, as, for instance, by the increase in the heart's

action and respiratory movements when one is walking or running. These conditions in their bearing on nervous action are, it is clear, somewhat abnormal, and unless neutralized or counteracted may be prejudicial.

The degree of ability to contract in a normal and not excessive manner is, in a certain measure, a criterion of the vitality of the tissues, and it is interesting to inquire in what way, if at all, this power may be developed. The problem is certainly a very difficult one. We know in the first place that, in contracting, any tissue must pass from a state of higher to one of lower oxidation. We also know that the degree of oxidation in the tissues is dependent on the mode of vibration of the nerve-cells, which control metabolism in the parts they supply. This being so, if the nerve-cells are by artificial means raised for a time to a state of increased oxidation, and then allowed, as the effect of the stimulus passes off, to sink little by little to a slower state of oxidation, the metabolism of the parts with which they are connected will, in a healthy subject *pari passu*, undergo similar changes. The inevitable nature of this change in nervous vibration was pointed out in dealing with physiological reaction, and though slight increases and decreases of oxidation and of contraction or expansion of the tissues are normal events, it is very essential to keep them within the fairly narrow limits of a healthy state. When the system has gone beyond these limits, recovery may to some extent be caused

Con-
tractility.

by producing effects which on the whole are opposed to the predominating condition, be that one of hyper-contraction or of hyper-expansion and relaxation. There are many ways of increasing oxidation in the nerve-cells, and some of these may be supposed to produce by reaction a constricting effect on the blood-vessels. Meat in general, and especially raw meat or a fresh extract of meat in which the action of the hæmoglobin has not been destroyed, stimulates oxidation. Whether they do this by reason of the chemical constituents with which they enrich the blood, or by causing a reflex action through the nerves of the stomach, is hard to say; but carnivorous animals are undoubtedly those in which muscular contractility is most developed, and which at the same time are most inclined to give themselves up to long periods of inaction. It is usually supposed that a cold bath produces a bracing or constricting effect, and though there is apparently no reason for doubting this, it is by no means clear how this result is brought about. The tissues in general, and especially certain parts, such as the hands and feet, show a tendency to swell with heat and to become constricted under the influence of cold. Heat, moreover, is more conducive to chemical action than cold. Is the effect of a cold bath, we may therefore ask, mainly a direct one accompanied by dynamic changes in the vibrations of the nerve-cells, or is it an indirect one caused by vaso-motor action at the periphery and in the nervous system? When cold water is applied in sufficient quantity to the skin,

a contraction of the subcutaneous bloodvessels may be supposed to take place, with the result that the internal blood-pressure and the supply to the internal organs, and presumably to the central nervous system, are increased. After a cold bath, however, every effort is usually made to bring the blood back to the skin, which, of course, implies a slight withdrawal of blood from the nerve centres, so that the latter may be supposed to pass from a higher to a lower state of oxidation. If we exclude the vaso-motor factor in its bearing on the central nervous system, it is rather difficult to understand how a bracing effect can be produced, seeing that the skin, owing to the friction to which it is subjected, receives a more abundant supply of blood after the bath than before. At the same time, though this movement of reaction is one of dilation, there is a general vaso-motor movement on a large scale, and this may give rise to secondary effects. On the other hand, the general effect of cold must be very great, or it would not be possible to allay fever by means of it, and in such cases the aim seems to be to produce a direct effect, and not one depending on reaction.

It seems highly probable that the contractility of the arteries is to a great extent dependent on the relative proportions of the two gases—carbonic acid and oxygen—which constitute, as it were, the limits in the movement of contraction; that is to say, in the movement from a higher to a lower state of oxidation. Although the amount of the former can be increased

by massage for a short space of time, yet it is very difficult to produce in this way the continuous yet fairly regular variations which obtain under conditions of health and rapid metabolism.

The influence of pre-existing conditions.

Nervous action, whatever may be its special features, always consists of certain groupings of the excitable molecules which constitute nervous matter. These groupings may be normal or they may be abnormal and pathological, and in both cases the degree of permanence of the character they possess will depend on the force and duration of the influences to which they are subjected. As bearing on the phenomena of metabolism, it may be said that absolute changes in the mode of vibration of the nerve-cells are very rare, especially in natures which are not hyper-sensitive or excitable. In passing from one set of conditions to another there is always something of the old influence still acting and blending with the new. This is a point which must be borne in mind in estimating the effect of residence at any given altitude, and, above all, in interpreting the results obtained from experiments in the pneumatic chamber.

Application of the theory of the ethereal nature of electricity to physiology.

No truly systematic theory of the nature of physiological processes can be evolved which is not based to some extent on conceptions of the fundamental relations of force and matter, or, to use the alternative phrase, of matter in motion. In this respect it therefore becomes necessary to refer briefly to certain possible deductions from the general views already expressed. We started, it will be remembered, by

supposing that the ether is matter in a state of infinite division; that matter itself as distinguished from free ether consists finally of atoms, which are in reality little whirling masses of ether, the specific motion of which gives them rigidity and assures their separate existence; that this specific motion is probably temporarily disturbed or in some way altered at moments of chemical action; and, lastly, that the free ether surrounds all molecules and atoms, thus permeating to a greater or less extent all forms of matter, and acting as a medium for the conduction of force proceeding from one sort or collection of molecules or atoms to another sort or collection. The force transmitted we suggested must be electricity. A difference of potential we further supposed to depend on the relative reactive power of any given class or collection of atoms as compared with another class or collection in respect to their properties of attraction and repulsion, and also on a second and extremely important factor, the state of tension of the ether. According to these views, and, indeed, according to any theory which admits the ubiquitous character of the ether, whenever chemical action takes place a disturbance of the ether must follow as a logical consequence. Whether or not it will take the form of a regular current depends, one would think, on the difference of potential between the substance in which action is first started and the surrounding substance, and on the regularity of such action. But the conditions in living organisms with respect to heat, movement, and

the loose character of the compounds comprising the various kinds of tissue, are so entirely favourable to chemical action that we may suppose the ether permeating them to be continually in a state of vibration. This we might infer from the existence of glandular, cutaneous, retinal, and other currents with which physiological research has made us familiar. Knowing that these currents exist in the body, not as solitary or haphazard events, but as regular concomitants of functional action, there are grounds for supposing, as we have already pointed out, that the ether may at times play the part of a conducting medium in many of those forms of chemical action in which, as far as one is aware, no nervous cells or filaments intervene in a direct manner. We are the more justified in assuming this to be the case, since the view that the passage of electrical currents, especially the faradaic, through the tissues will cause chemical action is fully admitted by specialists and members of the medical profession in general. Some noted French physiologists, as is shown by the passage quoted below,* have long been of opinion that

Views of
French
physio-
logists on
electro-
motory
action.

* Letourneau, 'Biology,' p. 213: 'To these conditions, already so favourable to the osmotic exchanges, are added electro-motory actions. This exceedingly interesting point of the physiology of the capillaries has been elucidated by M. Becquerel' ('Mémoires et Comptes Rendus de l'Académie des Sciences,' from 1867 to 1870) 'in a series of important papers. If by means of a voltaic pile we decompose water contained in a vessel divided into two compartments by a membrane, we see the level rise in the negative compartment. There is, therefore, material transport from the positive pole to the negative pole. Something analogous

electricity plays an essential and regular part in the complicated processes of metabolism.

As already mentioned, chemical action—that is to say, the agitation of atoms—could not take place in the tissues without affecting the ether surrounding them, and the influence they thus exert, if their action be regular, must of necessity be so also ; so that we have only to suppose electricity to be a mode of motion of the ether, and to conceive a difference of electrical potential as existing between the molecules on one side of a capillary wall, or a membrane and those on the other side, together with the usual conditions of heat, motion, and ethereal tension, and variations in the amount of oxygen, carbonic acid, and of the constituents of other chemical bodies, in order to explain the nature of the factors in metabolism. As regards the actual transport of atoms, this process is so strikingly analogous to that which is now generally

The
transport
of atoms
in an
electrical
cell and in
the body.

takes place in the capillaries. In consequence of the incessant chemical mutations which are effected in the tissues and the vessels, electrical currents are produced. The capillary is electrized negatively on the exterior and positively in the interior of its wall. The oxygen traverses the wall, and is deposited on the external surface. As to the globules, they enter into contact with the positive internal wall. The oxygen once filtrated into the tissues oxidizes them, and gives rise to the production of carbonic acid, which the electrical current tends to impel into the interior of the capillary. In other terms, and leaving aside the old notion of the two electric fluids, there is between the contents of the capillary vessels and the histological elements of the tissues a circular current—an electrical circuit—which carries the oxygen to the outside of the vessels and brings back the carbonic acid.'

regarded as the probable course of events in an ordinary electrical cell that there should be the less hesitation in accepting it as representing the truth, at least in its main lines.

Absorption in the
amœba.

In order to study the processes of nutrition in their simplest form it is necessary to begin by examining them, so far as that is possible, in some unicellular organism such as the amœba. We may imagine such a one to have encountered some little edible particle, and to be in the act of absorbing it. The granular protoplasm of the amœba separates to allow it to enter, pseudopodia are stretched out on either side; the body of the amœba then closes on the edible particle, which is thus held within it until much of the nutriment is withdrawn. By what forces is this brought about? What prompts the amœba to seize upon its food? Evidently there can be no question of chance impact. The particle is not driven into the amœba by a stray current, for any force of this kind would probably act on both alike. Moreover, if the particle were not edible the amœba would not stretch forth its pseudopodia, nor would its granular substance divide so as to receive it. But in order that a particle may be edible two things are necessary: it must be soluble and must be capable of undergoing oxidation; a particle answering to these requirements would show a marked tendency to enter into chemical action, and as soon as it collided with the more highly oxygenated substance of the amœba, a state of things decidedly favourable to development in this direction

would exist. Chemical action once started would cause, as is always the case, diffusion in the substance rendered active, and the entrance of the particle in the area adjacent to it would thus be provided for, or at least facilitated. The chemical action would, it may be supposed, cause some sort of vibration. Whether this would be molecular or electrical we cannot very well determine, though it seems natural to suppose that as in the case of the nervous impulse it would be of a compound nature. In any case, we may speak of it in a general way as an oxidation wave, and we may assume that it would cause in the nucleus also a slight amount of oxidation. These events constitute what one may term the chemico-sensory factors in absorption. Though more complicated they are of the same order in the higher animals. Hydrification and oxidation in one form or another are the chief processes. Chemical action, chemico-sensory impulses accompanied by diffusion or loosening of the surface in contact with the food—these are the common factors in absorption in high and low organisms, and to these must be added another, viz., motion, which may be recognised by the presence of muscular fibres in the mucous membrane of the intestines as it may in the thrusting out of the pseudopodia of the amœba. The exact nature of the latter event is, however, wrapped in considerable obscurity, although it seems to depend on certain events taking place in the substance of the amœba and in the nucleus.

The concatenation of automatic actions and reactions in digestion.

Secretion in the various portions of the digestive system appears to be connected in a certain measure with the chemical nature of the substances present in it. Thus, when the food, rendered slightly alkaline in the mouth by the saliva, descends to the stomach it causes a flow of acid, and it is a well-known fact that this effect can be increased by the use of weak alkalies. The acid acting on the carbohydrates of the food dextrinizes them, and dextrin has been called a peptogen because it augments the secretion of pepsin, an effect which, it is said, is still further increased through the presence of meat. The acidified food in turn, as it passes into the duodenum, acts as a natural excitant to the flow of the alkaline bile, which, mixing with the food, leads to further secretion in the glands of the remainder of the intestinal canal. Throughout the whole of the digestive tract there is, therefore, a concatenation of action and reaction due to chemical transformations in which differences of electrical, potential, and variations of ethereal tension are presumably, as elsewhere, a not unimportant factor. These facts lead to the conclusion that all the processes of metabolism, including those of digestion, are of an essentially electro-chemical nature.

The next step which it is necessary to take is to consider the relations existing between metabolism and the nervous system, and to discover, if possible, to what extent the force generated in the electro-chemical processes acts upon the nerve centres and in what degree the latter react.

In nutrition, as we saw in dealing with the amœba, there are two factors—a chemico-sensory or electro-chemical factor and a motor, in higher organisms a vaso-motor and intestino-motor factor. We know that both the bloodvessels and intestines have their respective motor centres in the medulla and spinal cord, and the point—a very difficult one—requiring consideration is whether nerve-cells are affected by the force liberated in the chemical processes of metabolism and to what extent. A question which presents itself, therefore, at the very outset of this inquiry is, Does chemical action give rise to nervous impulses? To this an affirmative answer may be given. Not only is it highly probable that our visual sensations are due to chemical processes which are started in the retina*—started in all probability by ethereal waves—but it is almost certain that those of smell and taste originate in a similar manner; that is to say, through chemical action. In the two latter cases a fluid is secreted by the glands of the olfactory and buccal mucous membranes, in which the particles to be smelt or tasted are respectively dissolved. Chemical force thus generated or liberated is at once transformed into nervous impulses. With these facts before us it seems natural to suppose that when chemical action takes place in the stomach, intestines, and other parts, as it does with greater rather than with less intensity, nervous impulses would in like manner result. Indeed,

Chemical
action as a
cause of
nervous
impulses.

* Foster, *loc. cit.*, pp. 1252, 1253.

it is difficult to understand how the nervous system can react upon the digestive and other metabolic processes unless it be affected by them. We may, it is true, conceive chemical action as acting directly on the bloodvessels or on the dilator nerves which supply them; but though some such action probably takes place, it is very doubtful if it be the only factor we have to consider, for motion in general is preceded by sensation or by its equivalent, in this case in the shape of an afferent impulse. Indeed, if we adopt the view that the dilation of the bloodvessels or the relaxation of the mucous membrane is the result of reaction on the part of the vaso-motor and other centres, we must perforce suppose that they have received a stimulus from the seat of activity. This stimulus is a factor which we can by no possibility get rid of if we admit the existence of reaction. In one shape or another it must reach the vaso-motor centre. But if, on the other hand, we suppose the same fibres to act as carriers of both sensory or afferent and motor impulses, or at least as discharging the dual function, we must imagine a dilating vibration to pass from the affected bloodvessel along the dilating fibre until it reaches the nerve-cell at the end of it, which would then take up the peculiar vibratory rhythm, adding force to it and thus reacting. That this course of events does not represent that which happens in some cases will be demonstrated by an example, but that it may occur in others is a possibility to which it is well not entirely to shut one's eyes.

Investigation into the nervous mechanism governing the secretory action of the submaxillary gland has revealed facts which, from the point of view of the matters just discussed, are of considerable interest. When food enters the mouth, the extremities of the lingual and glosso-pharyngeal nerves which are connected with taste, the former in the fore, the latter in the hind part of the tongue, are stimulated.* As a result of this, nervous impulses are carried along these nerves, and finally reach the centres of taste in the cerebral cortex. What paths they follow and what connections they set up is as yet but partly known. Simultaneously, however, other impulses travel, it is supposed, down the chorda-tympani† nerve to the gland, and cause a dilation of its blood-vessels and secretory activity.‡ The cortical perception of taste is not the most important part of salivation, and we must suppose that stimulative impulses travelling to the centre in the medulla oblongata,§ which governs the secretory process, are in reality more essential. Considerable doubt exists as to the true origin of the chorda-tympani nerve. Some look on it as arising in connection with the fifth, some as being a branch of the seventh or facial nerve. The lingual being a branch of the fifth, its relations to the chorda-tympani would be more easy to explain on the first hypothesis, but the evidence hitherto accumulated

Secretory
or
chemico-
sensory
nerves in
the sub-
maxillary
gland.

* Foster, *loc. cit.*, p. 1403.

† *Ibid.*, p. 399.

‡ *Ibid.*, p. 396.

§ *Ibid.*, p. 398.

does not warrant any definite statement. The chorda-tympani, moreover, is not the only nerve which modifies the vascular condition of the submaxillary gland. Filaments reach it following the course of the small arteries and proceeding from the superior cervical ganglion,* whence they can be traced back along the cervical sympathetic to the spinal cord, which they enter presumably by the anterior roots. The function of these nerves is to constrict the arteries and thus keep up their tone; but the part which they play appears to be of less consequence than that of the chorda-tympani, for section of the former will not prevent the flow of saliva, whereas when the latter is divided it ceases, and cannot be started afresh.

Direct
stimula-
tion of the
chemical
processes.

Again, experimental evidence tends to show that the chorda-tympani nerve possesses two sets of fibres, one of which acts as vaso-dilators, whilst the other—and this is extremely important—stimulates secretion in the cells of the gland in a direct manner irrespective of the blood-supply.† ‘Hence,’ says Foster in dealing with this point, ‘when the chorda is stimulated, there pass down the nerve, in addition to impulses affecting the blood-supply, impulses affecting directly the protoplasm of the secreting cells and calling it into action, just as similar impulses call into action the contractility of the substance of a muscular fibre.’ These facts and others of a similar nature relating to other glands seem to prove conclusively that the

* Foster, *loc. cit.*, p. 1403.

† *Ibid.*, p. 400.

nervous system is both acted on by and reacts upon the electro-chemical processes of metabolism.

At the same time, it must be constantly borne in mind that the two forms of force, the electro-chemical and the nervous, though convertible, are in a certain measure independent of one another. This fact has been strikingly illustrated in certain cases by the section of almost all the nerves of the stomach,* which led, contrary to expectation, to no arrest of the digestive processes, although it is well known that with the nerves intact under conditions of emotional stress or impaired health the chemical action of the stomach is frequently very much disturbed. If we keep these conditions of independence well in view we shall see that we are not justified in concluding that, because digestion will go on after section of most of the nerves, there are none possessing a secretory function analogous to that of the chorda-tympani. Why, then, it will naturally be remarked, does section of the latter nerve cause a cessation of the functional activity of the gland? But if we look deeper into the matter we shall notice that the conditions in the stomach and submaxillary gland, though analogous in many respects, are not so in others. In the former case, the materials to be digested are directly in contact with the secreting glands; in the latter case, there is a long duct intervening. Therefore there is greater need of nervous action or nervous collaboration in the submaxillary gland than in the stomach.

Relative independence of electro-chemical action and nervous action in metabolism.

Difference between secretory action in the submaxillary gland and in the stomach.

* Foster, *loc. cit.*, p. 403.

All nerves
and nerve-
cells are
concerned
in chemi-
cal action.

It will be well, however, to recall a statement which we made when discussing the nature of the nervous impulse. It was then pointed out that oxidation of a nerve-cell or of a collection of nerve-cells is the very essence of nervous action, at least, under normal conditions. It will be seen, therefore, that to this extent every nerve-cell in the body is concerned in chemical action or metabolism. But we may go even farther, for we may say that no action of any kind whatsoever takes place in any organism which does not lead either directly or indirectly to oxidation in the active part. If you do but press with your finger on the palm of your hand, you cause a temporary decrease in the rate of oxidation followed when reaction takes place by a proportional increase. If you lift a heavy weight from the ground, chemical action of an intense kind occurs, and in both instances it is governed by the nature of the sensory nervous impulses and their motor reaction. We must, therefore, perforce arrive at the conclusion that every nerve-cell and every nerve-fibre in the ordinary course of functional activity helps to regulate the processes of metabolism in the part it supplies. With respect to that metabolism which takes place in a state of repose, and in which the anabolic tendency is, there seems reason to suppose, especially marked, we may also believe that it is under nervous control, the latter being modified by the conditions which have existed during functional activity. How important the metabolism of repose is for the building up of nervous

matter which contains relatively but little oxygen has already been pointed out, and it would seem that a real gain in this respect can only be brought about when oxidation goes on after each fresh stimulus in a slightly decreasing rather than increasing manner.

In the effects produced upon the nervous system by sudden variations of temperature one may obtain further evidence, though of an indirect kind, of the modification which the state of contraction or expansion of parts of the nerve-cells undergoes as the nervous rhythm varies. The contracting influence of cold and the expanding influence of heat, it is scarcely necessary to say, are by no means limited to physiological processes, for with the exception of liquids in a freezing state, which are probably not true exceptions, all substances, whether organic or inorganic, are affected by them in the same way, though in different degrees. The molecules of living organisms behave, therefore, very much as do those of a piece of copper or iron; they separate under the influence of heat, though of course much more readily, and they draw together under that of cold. When the whole cutaneous surface of the body is suddenly exposed to the influence of cold, as in a bath, there is a general movement of contraction. That this movement is mainly vaso-motor may be granted, but that it is limited to the bloodvessels is apparently the case. The phenomenon known as goose-skin shows that muscular, and probably other elements such as the nerve-endings, take part in it. If the latter are

directly affected, then it is natural to assume that the nerve-cells with which they are connected are influenced in a similar manner, that the rhythm of their metabolism is suddenly altered, and that the molecules of which their protoplasm is composed, though still continuing to vibrate, are grouped in closer order. Indeed, if cold, like heat, be, as it is generally held to be, a distinct form of active force—and this view receives support from the phenomenon of freezing—it is but natural that it should act upon the nervous system dynamically; and if this be allowed it is difficult to conceive any other way in which it can act than that just suggested. If the arterial blood-pressure be normal, the contraction caused by the sudden application of cold will be accompanied by a diminution of oxidation in the nerve cells even when allowance is made for anything in the way of added tone to the arterial system, and the expansion caused by heat will be accompanied by a corresponding increase of oxidation when in the same way allowance has been made for the more relaxed state of the arteries.

A cool or cold bath, when there is no reaction, may be said to produce a general effect of peripheral constriction and a diminution of oxidation in the nervous system, and thus throughout the body. To obtain this result it is employed in cases of fever. In this way the metabolic rhythm of the nervous system is altered, and it is brought from a state of excessive to one of diminished oxidation, and at the same time

from a condition of constant loss, since in fevers the breaking down of tissue exceeds the building up to one of equilibrium, and eventually to one of gain ; indeed, the change of rhythm is sometimes of so decided a character that a person may become very much stronger a little time after an illness than before the attack. We therefore see that a certain degree of contraction in the nervous rhythm is absolutely essential to anabolism, for contraction in this case is synonymous with attraction. We can very easily bring about a certain degree of contraction in the nerve-cells by the simple application in one form or another of cold to part or to the whole of the skin, and this is a point of great importance. But it is not all, for in so doing we run a risk of producing a marked tendency towards stagnation. We pass from a state of excessive metabolic action to one of insufficient action. The nervous metabolic rhythm, after having been on the side of excessive expansion, reverts to that of excessive contraction, and the body, after having expended its forces in riotous living, is suddenly pinched and starved like that of the prodigal. In the hyper-contracted state the nerve-cell does not possess that amount of mobility which is essential to the maintenance of vital energy at its maximum. On the other hand, if the nerve-cells be allowed to fall back into a rhythm characterized by too great expansion, there will be a loss both of energy and, a perhaps more important matter, of actual material or tissue. The general aim in

nervous treatment may therefore be defined as being to make the state of contraction predominate slightly over that of expansion, and to stimulate nervous mobility chiefly within the limits of the former.

When a cold bath is followed by a sharp return of blood to the skin a double effect is produced, for a note of contraction and diminished oxidation is struck, succeeded immediately by one of expansion and increased oxidation. The nervous metabolic rhythm acquires under these conditions a dual character, with an increased tendency in both directions, but mainly, it would seem, towards contraction. In those whose nervous system is well balanced the normal rhythm is soon re-established. Those, however, the protoplasm of whose nerve-cells has been constantly contracted and expanded in an exaggerated manner through indulgence in alcohol, or through too free consumption of food-stuffs, or medicaments containing alkaloids, or through repeated and intense increases and decreases of oxidation caused in other ways, or, again, through hereditary tendencies due to the heavy drinking habits of parents or ancestors, such persons will naturally be influenced in an excessive degree by the cold bath. In young people, when there is excess, it is generally on the side of contraction, whilst in old people the reverse is sometimes the case. One of the commonest results of treatment in the way just described is to produce cold hands and feet. This illustrates the mode of action of the bath in such cases, for we have clear

evidence of both vaso-constriction and diminished oxidation. Severe indigestion is also frequently due to a similar state of excessive vaso-constriction and diminished oxidation, and habitual sleepiness may be attributed to the same cause. Amongst the signs of relaxation, due to a predominance of the expansive tendency, are hot hands and feet, insomnia, and constipation.

In respect to the influence which a cold bath with a marked reaction may exercise through the vaso-motor centres, the first point to consider is the continuous character of vaso-motor action. Each beat of the heart causes movements of expansion and contraction in the whole arterial system which are intensified by the bath. That this pulsation is lost before it reaches the capillaries and tissues is well known, so that it is impossible to trace any direct effect on metabolism in this direction. On the other hand, however, it is perhaps not impossible that a dynamic effect may be produced upon the whole nervous system, owing to its relations to the vaso-motor centres, in which case the character of the metabolic processes would be affected. But whether the nervous system, and with it metabolism in general, be influenced by heat and cold directly or only through the medium of vaso-motor action, the effects produced on the one are felt in like manner in the other. Constriction of the bloodvessels, in any part if at all excessive, as in the case of cold feet, must inevitably be accompanied by a corresponding diminution of

oxidation. This is chiefly important because of the relation which anabolism, or the building up of tissue, bears to the general state of contraction of both the arterial system and the tissues, together with the nervous metabolic rhythm. If the arteries, instead of being normally contracted, are too relaxed, the tissues coming under the same general influence will be too relaxed, and the metabolic rhythm of the nerve-cells on which the metabolism of the tissues depends will be too relaxed also. The holding power of both the tissues and the nerve-cells will therefore be diminished, and metabolism in them, though not wholly katabolic, will nevertheless incline to the side of katabolism rather than to that of anabolism.

If we admit that expansion and contraction are essential elements in metabolism, either owing to the relations existing between the vaso-motor centres and the rest of the nervous system, or for reasons of a more direct nature, we may compare nervous action in general to the behaviour of a piece of elastic band at rest or under tension. You cannot make the band contract unless you have previously stretched it; but the more you stretch it, especially if you overstretch it, the less forcibly in the end will it contract. By degrees, as it becomes worn out, it will appear drawn together and crinkled, and is weak and limp. So it is with the nerve-cell. At first, we may suppose, it is well filled and plump, but by intense vibratory action accompanied by an excessive blood-supply, which is

the same as the overstretching of the elastic band, it loses substance, and with it elasticity. In this way the rhythm of the cell becomes like the state of the elastic band, sometimes too contracted and sometimes too relaxed. At the same time it will be understood that, in speaking of the contraction and expansion of the nerve-cells, only that degree is implied which one would suppose to be necessary to produce a change of rhythm going on amongst the molecules of the cells, and without which, indeed, such a change is inconceivable. The more highly pathological the nervous rhythm is, the greater must be the degree of contraction or expansion in the tissue of the nerve-cell. Though under normal conditions it is doubtless very slight, yet it must always be an essential factor in nervous action.

It will be evident to everyone who reflects for a moment that, if contraction and expansion are the very essence of vaso-motor action—and hence of the activity of the vaso-motor centres—any drug which acts upon the latter must increase the tendency in one direction or the other. It may cause increased contraction for a time, and then give rise to a reaction of increased expansion when it ceases to act; but in so doing it must diminish somewhat the equilibrium between these opposite tendencies, and it cannot bring about that alternate movement from one state to the other which takes place with every beat of the heart, and on which, as a great physician has said, the health of the whole arterial system depends. Nor

can you obtain this result by any combination of drugs of opposite tendencies, for they must one and all modify the environment of the nerve-cells, and thus alter the character of their rhythm, acting on them simultaneously, and not, as would be necessary if they were to promote general vaso-motor activity, alternately. By means of a cold bath with a certain amount of reaction it is possible to bring about both contraction and expansion, although it is difficult to regulate the degree of each. By means of rapid changes from a warm to a cooler bath, and *vice versâ*, one can stimulate both vaso-motor action and metabolism. The influence of such baths, however, is very powerful, and although under certain conditions it may be highly beneficial, yet at the same time it may also be the reverse. If by this means metabolism is set going very rapidly, it is absolutely essential to control the general tendency of it—to keep it, that is to say, with the balance slightly on the side of contraction and anabolism. One cannot put the matter more truly than by comparing the process to the riding of a bicycle. The short movements of the handle-bar to this side or that enable you to travel quickly and smoothly, but unless you pursue a given direction you will run into the wall or the gutter. That it is very difficult to maintain a predominance of contraction over expansion in the arterial system when it has become thoroughly relaxed is true, but at the same time it is equally certain that in this way only, and by keeping up vaso-motor mobility, it is

possible to insure an anabolic rather than a katobolic character in metabolism.

Hitherto we have dealt with the nervous system in its normal condition, but it is possible by means of electricity to raise it to a higher state of tension than usually prevails, and the effects produced under these circumstances have certain features which are of interest: they are more intense, and in many cases, perhaps in the majority, they are the result of reaction. Electricity, as has been pointed out already, has no physiological character of its own, nor can it transmit any save that which it borrows from such other agencies as constitute the environment of the body during the period of electrification. The results obtained from the use of it may be ascribed partly to the intense vibration which is caused and to a slight increase in the tendency to vibrate which remains as an after-effect, but also in many instances to the sudden cessation of this vibration, whereby the character of the nervous rhythm is changed. The benefit or harm which is likely to result from electrical treatment depends, therefore, much less on the electricity itself than on the conditions under which the electrification is carried out. Electricity can, in a word, give greater nervous mobility for a time, but it cannot alone determine the character which that mobility may assume. When electricity is administered in a bath there are certain factors which deserve attention. If the temperature of the water be above blood-heat it is evident that the nerve-cells,

the degree of tension being raised, will be thrown into a state of abnormal vibration under an expanding influence ; and when at the termination of the bath this influence is, as always happens, suddenly removed, it is only natural that a change in the nervous rhythm should take place, and that it should be in the direction of contraction. On the other hand, if the bath be below blood-heat, the change of rhythm or reaction would be towards expansion. Owing to the fact that the nervous system is raised during the passage of the electric current to a higher state of tension, the effects produced are likely to be in most instances of a comparatively more permanent nature than is the case when a simple bath is taken. The effect of an electric bath may also be said to depend to some extent on the state of the blood-pressure in the nerve-centres as determined by the position of the body, especially if the electrodes be applied to the spine or head. Variations of blood-pressure affect a delicate nervous system even without the application of electricity. Many persons sleep better on a high pillow ; many, also, do not enjoy perfect repose when lying on the back. An increase of blood-pressure in the nerve-centres causes an increase of expansion and greater activity, hence the tendency to wake or dream when one is lying on one's back. Under the influence of the electric current these effects are increased, and accordingly the reaction or change in the nervous rhythm, which takes place when the current is cut off, is correspondingly greater. Similar, though still

more intense results may be expected when a patient, as doubtless often happens, takes an electric bath under the influence of a drug. There also seems to be some reason for supposing that the altitude of a place may contribute in some measure to the ultimate effect produced by electrification. For instance, if we suppose a person to go suddenly from sea-level to a locality 1,000 or 2,000 feet higher, and to undergo electrical treatment for some weeks, it is likely that the nervous rhythm would be considerably influenced by the diminution of atmospheric pressure, and that the molecules of the nerve-cells would be tuned in their movements to expansion rather than to contraction. When, however, electric baths are taken very frequently, the intense vibration may, in the long-run, exert an expanding or relaxing influence which will outweigh all other influences.

CHAPTER II

THE SPINAL CORD AND THE FUNCTIONS OF THE CEREBELLUM

The chief features of the spinal cord—The gray matter—Tracts in the white matter—Fibres of the spinal nerve-roots—Their functions and connections—Fibres of the posterior root—The sensory and motor elements in the cord—The fine fibres of the posterior roots—Other tracts—Functions of cells in the anterior horn of gray matter—In the lateral horn—In the posterior horn—Function of the pyramidal tracts—An idiolateral pyramidal tract—Of the intermediate bundle—Of the fundamental groups—Of the posterior columns—Functional correspondence of elements in the two horns—Size of nerve-cells and thickness of fibres as a criterion of function—Increase of impulse-cells—The nervous factors in the local augmentation of activity in an organism—Increase in the sensory stimulus is chiefly due to internal causes—The physiological mechanism of will—The part of the increase of impulse-cells in involuntary action—The nature of desire—Points of resemblance between the cells of Purkinje and those of Clarke's column—Opposite views respecting the functions of the cerebellum—Pathological evidence—Ferrier's facts—Luciani's cases—Ferrier's views opposed to Luciani's—Cases of defective development of the cerebellum—Co-ordination is possible in the absence of the cerebellum—Secondary centres of the cerebellar system—The factors in equilibration—The anatomical elements in equilibration—The cerebellum in voluntary action—The relationship between parts of the

cerebellum and groups of muscles—Anatomical relations of the cerebellum—Relations of the cerebellum to the spinal cord—Bechterew's classification—Brief summary of the pathological evidence—Development of the cerebellum—The chemical or nutritive influence of the cerebellum in equilibration—The cerebellum as a reinforcing organ—Its relations to the vaso-motor centre—Does the cerebellum influence chemical action directly?—Chemical action as a constant element in nervous activity.

It is essential at this stage to call to mind some of the chief features of the spinal cord. Though, roughly speaking, of a circular shape, it is divided like the brain itself into two halves. This division, which is not absolute, is caused by an anterior and a posterior fissure, the latter the deeper of the two, being in reality a septum or membranous partition rather than a fissure. Each half is made up of a more or less central portion consisting mostly of nerve-cells and a peripheral or external portion composed chiefly of nerve-fibres. These fibres are divided throughout the whole length of the cord into three main columns—the anterior, lateral, and posterior. Issuing from the cord between the vertebræ at slightly irregular distances proceed on each side the spinal nerves by two roots, the anterior root passing out from the anterior horn through the anterior column, whilst the posterior root divides the posterior from the lateral column.

The chief features of the spinal cord.

The spinal nerves are mainly channels of sensory and motor impulses, and they differ greatly in size in accordance with that of the parts they supply, those which are distributed to the arms and legs being very

large, and those passing to the muscles and sensory surface of the trunk being proportionately smaller. These conditions are reflected in the cord itself, and especially in the size of the gray matter, which in the lower cervical or neck portion—whence the nerves of the arms proceed—and in the lower lumbar and sacral portion—whence the nerves to the leg issue—is very considerable, whilst in the intervening dorsal region its dimensions shrink to one-half or one-third of the extent occupied by it in the localities just mentioned.

The gray
matter.

The gray matter is divided into a so-called anterior or ventral and posterior or dorsal horn, to which a lateral horn is sometimes added, and comprises several groups of cells which increase, diminish, or disappear as one passes up or down the cord. Thus, there are median, central, ventro-lateral, and dorso-lateral groups. Most of the cells of the ventral horn are supposed to send fibres into the anterior roots of the spinal nerves,* the impulses passing along them being motor either to the muscles or to the bloodvessels of the body and limbs. The dorsal horn is composed to a great extent of masses of intersecting fibres termed the lateral and posterior formations. There is, however, in addition an important group of cells called the vesicular cylinder or Clarke's column. It extends from the eighth cervical to the third lumbar nerve, at which points it is interrupted, reappearing, however, between the second and third cervical nerves, and

* Foster, *loc. cit.*, p. 936.

possibly, it is thought, in the sacral region also* and in the bulb above the spinal cord. These cells, it is held,† are not connected with the motor fibres which go to muscles nor with the ordinary sensory fibres, although they do receive fibres from the posterior or sensory roots, as we shall presently see in greater detail. Besides the three great divisions before mentioned the white matter is divided into numerous tracts. The posterior column is divided by a septum into the postero-median and postero-external columns. Separated from the last-named by the fibres of the dorsal root is the cerebellar tract, which, throughout rather narrow, stretches forward along the margin of the cord almost to its anterior surface. Between this and the gray matter lies the crossed pyramidal tract, whilst following the margin of the cord forward from the cerebellar tract we have the antero-lateral ascending tract with the antero-lateral descending tract, and the direct pyramidal tract at its extremity bordering on the anterior fissure. Of these tracts, three—the median posterior, the cerebellar, and the antero-lateral ascending—are termed ascending to signify that they are supposed to carry impulses upwards to the brain, whilst three—the crossed and direct pyramidal and the antero-lateral descending—are called descending tracts for a corresponding reason.‡

Tracts in
the white
matter.

The connections and functions of some of these tracts are but partly known. Fairly well defined,

* Foster, *loc. cit.*, pp. 956-958.

† *Ibid.*, p. 958.

‡ *Ibid.*, p. 945.

however, is the great crossed pyramidal tract stretching from the cerebral cortex to the large cells of the anterior horn of the gray matter of the cord, which serve to connect it with the anterior roots of the spinal nerves and so with the muscles of the body and limbs. The direct pyramidal tract is so called because its fibres pass down the same side of the cord, crossing, however, before they make their connection with the anterior roots of the spinal nerves through the cells of the ventral horn.* The median posterior tract is composed chiefly of coarse fibres derived from the posterior or dorsal root of the spinal nerves, which to reach it pass through the external posterior tract lying adjacent to it. This has been said to be the chief path of sensory impulses to the brain,† but all physiologists are not agreed on this point. The posterior roots furnish other fibres, which pass inwards to the vesicular cylinder‡ and other cells of the gray matter. These are especially interesting, for although forming part of the dorsal or sensory root, they lead to cells which, as already stated, are not held to be sensory in the ordinary acceptation of the term. The fibres of the cerebellar tract take their origin in the cells of the vesicular cylinder just mentioned, and pass up the cord on the same side to the cerebellum.§ It is said to begin rather suddenly at the level of the second lumbar nerve. In addition to the above tract the cerebellum by its superior peduncle receives the

* Foster, *loc. cit.*, p. 962.

† *Ibid.*, p. 950.

† *Ibid.*, p. 967.

§ *Ibid.*, pp. 962-964.

fibres of the antero-lateral ascending tract, which are derived either from the vesicular cylinder or from cells adjacent to it.*

The fibres of which the roots of spinal nerves are composed are derived from many sources, but it is possible to classify them, to some extent, according to the parts which they supply and the nature of the impulses they carry. When the fibres of the common trunk are traced along their paths to the periphery, some are found to end in muscle, some in sensory end organs or sensory surfaces, and some in the sympathetic ganglia. These latter constitute an important chain stretching the whole length of the spinal cord on either side. They are sometimes looked on almost as a separate nervous system, but this view is only justifiable in a limited extent. Like the parts which they chiefly supply they are contained for the most part in the body cavity, and acquire greater size and importance in special regions. They have a double connection with the spinal nerves, the one link being the white ramus communicans, the other the gray ramus communicans, which sends a recurrent branch to the bloodvessels of the limbs.† These ganglia are connected with the viscera of the body, and as these are composed chiefly of muscular tissue, of sensory or chemico-sensory surfaces or membranes with their glands, and of bloodvessels, it seems natural to suppose that the functions of the fibres passing through the ganglia will be motor to the muscular

Fibres of
the spinal
nerve-
roots.

* Foster, *loc. cit.*, p. 971.

† *Ibid.*, p. 171.

tissue of the viscera, vaso-motor to the bloodvessels, and chemico-sensory to the mucous membranes or tissues where the chemical processes of digestion and metabolism are started. Besides the fibres proceeding from the ganglia of the sympathetic system there are others which affect the calibre of the visceral bloodvessels.* Referring to the abdominal splanchnics, which are mainly sympathetic, Foster says: 'The majority of these splanchnic fibres seem to be efferent in nature, carrying impulses from the central nervous system to the tissues, some ending in plain muscular fibres, others in other ways; but some of the fibres are afferent, and convey impulses from the viscera to the central nervous system, and it is probable that some of these begin or end in epithelial cells of the viscera.'†

Their
functions
and con-
nections.

Passing now from the common trunk of a spinal nerve, embracing as it does fibres from the muscles, bloodvessels, and sensory surfaces of, in some cases, both the limbs and viscera, and in other cases of the body and viscera, it will be interesting to follow as far as possible the distribution of the various strands of fibre in the nerve-roots. The anterior root contains fibres which proceed to the skeletal muscles and to the muscular tissue of the bloodvessels, and others which are said to be secretory.‡ Whilst some of its fibres come directly from the large cells of the ventral horn of gray matter, others can be traced to the small cells

* Foster, *loc. cit.*, p. 172.

† *Ibid.*

‡ *Ibid.*, p. 949.

of the same region, others pass towards the dorsal column, to the lateral column, and by what is termed the white commissure, to the opposite side of the cord.* Some of the fibres of the anterior roots are coarse and some are fine; and it is natural to connect the former with the skeletal muscles and the latter with the vaso-motor, secreto-motor, and possibly secretory functions, and, as Bechterew suggests, with the muscular tissue of the intestines. The last-named physiologist quotes Gaskell's opinion that the fine fibres of the anterior root are connected with the tract of gray matter known as the intermedio-lateral, with the post horn, and with Clarke's column. The importance of this lies in the fact that fine fibres from the posterior root seem to terminate in the same locality or very near to it.

The fibres of the posterior root may be divided into two or three principal bundles. Of these, one termed Fibres of the posterior root. the median, consisting of coarse fibres, passes into the external posterior column, and thence into the postero-median column, carrying, it is thought, a great proportion of the sensory impulses to the cerebral cortex. Some fibres also pass to the vesicular cylinder or Clarke's column, the large long cells of which have been observed to be imbedded in fibres.† The second bundle, called the lateral, is divided into an intermediate bundle consisting of coarse fibres, which pass directly into the gray matter of the posterior horn, and a more external portion, composed of fine

* Foster, *loc. cit.*, p. 949.

† *Ibid.*, pp. 934, 935.

fibres, which run longitudinally up the cord for some distance between the posterior horn of gray matter and the crossed pyramidal tract.*

The distribution of the fibres of the posterior root is complicated by the fact that on entering the cord they are seen to divide, one portion running upwards and one downwards, and, further, by the giving off of collaterals or branches to other cells in the cord. Some of the fibres, it will be seen—indeed, the great majority—are coarse, whilst a smaller number are fine. Most of the former travel upwards towards the spinal bulb; some, however, pass to Clarke's column, whilst others either join the substantia gelatinosa of the dorsal horn, or make connections with the motor cells of the ventral horn, or, again, find their way to the opposite side of the cord.†

To thread the tangled maze of fibres thus arranged is a very difficult task; yet one thing seems tolerably clear—the directions which they take indicate differences of function. If they do not tell us definitely what the part of each set of fibres may be, yet they furnish us with some data on which to base certain conclusions. Knowing that the posterior root is the sensory portion of each spinal nerve, and that the cerebral cortex is the seat of perceived sensation, we have reason to believe that those fibres which pass upward towards the spinal bulb, and then by means of certain relays—as to the nature of which some of the highest authorities are not agreed—establish a con-

* Foster, *loc. cit.*, p. 949.

† *Ibid.*, p. 950.

nection with the cortical cells, are very important sensory channels.

Those fibres which pass to the motor cells of the ventral horn and those which cross the opposite side of the cord seem by reason of their connections to be of a co-ordinating nature. They bring, so far as one is able to judge, one part of the nervous system into relation with another. What, then, is the function of the remaining fibres of the posterior root, both coarse and fine? It will be remembered that the anterior root was said to be composed of motor, vaso-motor, secretory, and perhaps secreto-motor (to the muscularis mucosæ) fibres; and one is the less inclined to look for a reduplication of any of these in the posterior root, since it is the sensory root. Motion and sensation are most closely allied, although distinct; and probably in all organisms the former is the consequence, and, one might almost say, the continuation, of the latter. They represent, as it were, the wave and counterwave in a vibratory movement. The whole architecture of the spinal cord, the division of its gray matter into what one may look on as a motor and a sensory horn, the distribution of its white matter and of the nerve-roots in a corresponding manner—all this seems to be based on the fact of the anatomical difference between sensation and motion.

But if for this reason one should put aside all motor impulses, excluding at the same time any which might be termed purely co-ordinating, and those which are sensory in the ordinary sense, and are believed by

The sensory and motor elements in the cord.

The fine fibres of the posterior roots.

some physiologists to follow a direct path to the bulb, the question again presents itself, What may be the function of the remainder which are connected with cells in and around the posterior horn? The anterior horn is, one may believe, mainly motor. Is the posterior horn merely a centre of co-ordination, or is it mainly sensory? If it be sensory, are not the fibres which, proceeding from the posterior root, end in it also sensory? Again, if they be sensory, what form of sensation can we allot to the coarse and what form to the very fine fibres? Does it not seem likely that the latter are connected with some of the more delicate chemical processes of metabolism? The visceral nerves in general are remarkable for their delicacy of calibre, and if a portion of their fibres are connected with vaso-motor functions, and a portion with secretory or chemical processes, those belonging to the latter category might be supposed to be of very fine structure.

The circulation of the abdominal region is remarkable, not only because of the plentiful supply of blood-vessels, but because the variations to which it is subject are probably greater than in any other part of the body. The nerves of the intestines must for this reason include many vaso-motor fibres, and their distribution on reaching the cord must correspond, one would suppose, in some measure to the position occupied by these organs. Although the distribution in the spinal cord of the abdominal splanchnics or vaso-motor nerves to the intestines is a matter of great complexity, one may probably assume that they

make connections in the spinal cord in the lower dorsal and lumbar regions.* If in addition to vaso-motor fibres these nerves constitute paths for secretory or chemico-sensory impulses, then we should have the two presumably essential factors in nutrition, and we might reasonably infer that this portion of the cord is in a special manner connected with functions of this order. As regards the lumbar portion of the cord, there is, indeed, distinct evidence that it is functionally concerned in keeping up the nutrition of certain parts of the body; for when in a dog it is severed from the rest of the cord, but otherwise left intact, the animal may, if carefully treated, be kept alive and in very fair condition, whereas if the lumbar section be not only separated but destroyed, the nutritive processes, especially in the hind limbs, become disordered and death ensues.† Bed-sores and impaired nutrition are also frequently the consequence of injury to the spine.‡ This seems to indicate that there are certain cells in the cord itself which play an essential and important part in the nutrition of the body. That some cells in the lumbar portion are specially concerned in keeping up and giving power to the other nerve-cells is certainly suggested by the satisfactory state of nutrition after separation. From the above facts and from the anatomical relations of the abdominal splanchnic nerves to the cord one would be inclined to infer that somewhere in the lower dorsal

* Horsley, 'The Brain and Spinal Cord,' p. 116.

† Foster, *loc. cit.*, p. 986.

‡ *Ibid.*

or lumbar portions important centres are to be found for the digestive and renal organs.

This carries us one step further, but here our difficulties really begin. We may be able to specify the kinds of impulses which are likely to proceed from the digestive organs by analyzing the various forms of action of that region. We may group them with reference to their course by the motor and sensory roots of the spinal nerves with at least a certain degree of probability; but when we enter the spinal cord itself, and seek to trace the paths they follow and the nerve-cells with which they are connected, we tread upon ground where exploration, though actively pursued, has as yet yielded but, comparatively speaking, few definite results.

Other
tracts.

In addition to the direct and crossed pyramidal tracts there are a few scattered fibres in the latter of these, to which the term *idiolateral pyramidal tract* has been applied. The reason for this is that a cerebral lesion in one hemisphere will give rise simultaneously to degeneration, not only in the direct and crossed pyramidal tracts, but in the crossed pyramidal tract of the same side as the hemisphere affected.* In the posterior column, besides the outer portion called Burdach's column, and the inner portion called Goll's column, there is a small tract, more centrally placed, spoken of as the 'descending comma tract.' It is supposed to be composed—at least in part—of the descending portions of the posterior root-fibres which

* Foster, *loc. cit.*, p. 942.

branch as they enter the cord, and as these portions are short, degeneration when it occurs is limited in extent. Both Burdach's and Goll's columns are said by Bechterew to contain many fibres which do not pass directly to the medulla oblongata, but at successive levels form connections with the gray matter of the cord.* In the external posterior tract close to the point where the posterior roots enter the cord, there is a further subdivision of the posterior column, called the posterior root-zone, the fibres of which pass almost directly to the gray matter of the cord, and in addition to this there is a small zone of very fine fibres, called Lissauer's zone, lying close to the tip of the dorsal horn, and owing its origin also to the posterior root.†

* Bechterew, 'Die Leitungsbahnen im Gehirn und Rückenmark,' pp. 58, 59: 'Es ergibt sich hieraus der Schluss, dass die zarten Stränge vorwiegend aus langen Bahnen bestehen, welche zum grossen Teil ununterbrochen bis zu den gleichnämigen Kernen der oblongata emporsteigen, dass die Keilstränge hingegen der Hauptsache nach ein Gefüge kürzerer Fasern darstellen. Beide Stränge enthalten übrigens, wie erwähnt bis zu einem gewissen Grade Fasern von gleichem Ursprung.' Page 60: 'Rücksichtlich der Lage der Wurzelfasern in den Hintersträngen lehren neuere Untersuchungen, dass jede neu eintretende Wurzel stets lateralwärts von den bereits eingetretenen zu liegen kommt und letztere medianwärts verdrängt. . . . Hierbei ist nicht zu vergessen, dass in den proximalen Teilen des Markes überhaupt nur wenig Fasern aus distalen Gegenden zu treffen sind; die Mehrzahl der letzteren biegt schon vor Erreichung der oblongata in die graue Substanz um, und von hier gelangen dann in die Hinterstränge weitere Fasern, welche offenbar die in der grauen Substanz unterbrochenen Hinterwurzeln centralwärts fortzusetzen bestimmt sind.'

† Foster, *loc. cit.*, p. 945.

The fact that the cerebellar tract does not undergo degeneration when the posterior nerve-roots alone have been severed, but only when the cord itself is injured,* shows the connection between it and the spinal nerves to be an indirect one.

The remainder of the white matter of the cord—that is to say, the greater part of the anterior division and a considerable part of the lateral division—has been differently defined by various writers.

The fibres of the antero-lateral ascending tract are supposed to take their origin in the middle zone of the gray matter, and often degenerate in company with those of the cerebellar tract.† Those of the antero-lateral descending tract, apparently described by Bechterew and Marchi as the anterior-marginal bundle, occupy a position parallel and close to those just mentioned, and are said to be connected with the cerebellum and to constitute a path for centrifugal impulses.‡ Internal to the antero-lateral ascending and descending tracts and the crossed pyramidal tracts, between these and the gray matter are the anterior and lateral fundamental tracts;§ whilst immediately between the crossed pyramidal tract and the posterior horn of gray matter is situated a tract called by Bechterew the median bundle of the lateral column. According to the same author there is also a tract of fibres in the centre of the crossed pyramidal tract which undergo descending degenera-

* Foster, *loc. cit.*, p. 963.

† Bechterew, *loc. cit.*, p. 89.

‡ *Ibid.*, p. 81.

§ *Ibid.*, p. 84.

tion when the inferior peduncle of the cerebellum has been severed. To these he has applied the term 'intermediate bundle.'* Of the fibres of the antero-lateral fundamental tracts, which are sometimes grouped together, some are connected with cells of the anterior horn, some through the anterior commissure with the posterior horn of the other side—and especially with the cells of Clarke's column—whilst others pass to the gray substance between the lateral and posterior horns of the gray matter.†

The cells of the gray matter, which are held upon evidence which is fairly conclusive to be motor to the skeletal muscles, occupy a position rather to the external side of the anterior horn, forming what is termed the lateral or limb group. Another group called the median is situated on the inner side of the horn towards the anterior fissure, and is especially conspicuous in the thoracic portion of the cord. It is said by Bechterew to be composed chiefly of commissure cells connected with the opposite side of the cord.‡ At the base of the horn and near to the anterior commissure and central canal is a third group of smaller cells, also belonging to the same region, and very scantily represented in the cervical and lumbar portions. It is held that the median group is essentially distinct from the lateral group, and there seems to be some reason to suppose that the latter is not represented, or is represented to a

Functions
of cells in
the an-
terior horn
of gray
matter.

* Bechterew, *loc. cit.*, p. 97.

† *Ibid.*, p. 78.

‡ *Ibid.*, p. 25.

slight extent only in the thoracic region. Evidently, if this be so, the lateral group must differ in function from the others, and if the median group be as suggested, commissure cells, it seems natural to connect the group of smaller cells at the base of the anterior horn with vaso-motor or secreto-motor functions.

In the
lateral
horn.

A group of cells has been defined in the lateral horn which is well marked in the thoracic region, and is discernible in the lumbar region, but becomes confused with the lateral group of the anterior horn in the cervical portion of the cord. This group is thought to be motor to the intestines.*

In the
posterior
horn.

Two groups, known as the posterior lateral reticular formation and the lateral reticular formation, occupy a position about the centre of the posterior horn, which, roughly speaking, they bisect. They are found throughout the cord, being most conspicuous in the cervical region. Near the base of the posterior horn, on the inner side, is a very important group of cells already mentioned, viz., the vesicular cylinder or Clarke's column. The cells of this group are large and fusiform. They lie with their long axis lengthways along the cord, surrounded by, or, as it were, embedded in, a mass of fibres. This group is very prominent in the central portion of the cord, extending from about the eighth cervical nerve to the third lumbar nerve. It has been recognised again opposite to the second and third cervical nerves, and is

* Bechterew, *loc. cit.*, p. 26.

supposed to be present in the sacral region and in the medulla oblongata.* The region of its greatest development is the lower dorsal and upper lumbar. The axons or main fibres of these cells are coarse, and pass, as stated, to the inferior peduncle of the cerebellum forming the cerebellar tract.

In attempting to determine the functions of the various parts of the white and gray matter of the cord, it is necessary to consider, firstly, their anatomical relations so far as these happen to be known; secondly, the size of the cells and fibres; thirdly, the nature of the impulses, chemical, sensory, or otherwise, which may constitute a part of their environment; and, fourthly, the character of the degeneration they undergo after section or in pathological cases.

By a very general consensus of opinion the direct and crossed pyramidal tracts have been set aside as the chief, if not sole, paths of motor impulses to the skeletal muscles. They both end by forming arborescences round the large cells of the anterior horn.† The fibres of the direct tract‡ are said to cross by the anterior commissure, but this has been denied.§ The united pyramidal tract as it passes down through the lower parts of the brain from the cortex of the

Function
of the
pyramidal
tracts.

* Foster, *loc. cit.*, p. 957.

† Recent research, I have been informed, has revealed a connection between the pyramidal tracts and the cells of Clarke's column.

‡ Foster, *loc. cit.*, p. 962.

§ Bechterew, *loc. cit.*, p. 94: 'Der vordere Pyramidenstrang hat demnach Beziehungen zu Nervenzellen des gleichseitigen, nicht aber zu solchen des entgegengesetzten Vorderhornes.'

cerebrum to the pyramid makes connections with several cranial nerves, whilst its fibres also give off collaterals to form similar connections in the spinal nerves.* These connections may be held to constitute part of the co-ordinating system of the body, whereby the muscles are brought into functional relations with the sense organs and with one another.

The idio-
lateral
pyramidal
tract.

The function of the remaining tracts of fibres which are intimately connected with or which form part of the pyramidal system is more difficult to determine. One of these, the idiolateral, occupying, it will be remembered, the same position in the cord as the contra-lateral fibres of the crossed pyramidal tract, and being mingled with them, undergoes degeneration, according to Foster, when a lesion occurs in the hemisphere of the same side. The other, described by Bechterew as occupying a position in the crossed pyramidal tract almost identical with that of those just mentioned, degenerates when the inferior peduncle of the cerebellum is severed. It consists, indeed, of the group of fibres termed the intermediate bundle or tract, which, proceeding from the cerebellum, join the pyramidal fibres in the medulla oblongata. Severance of the inferior peduncle, however, not only leads to degeneration in their fibres, but also in the crossed pyramidal fibres of the same side, and even in those of the anterior roots of the spinal nerves.†

Of the
inter-
mediate
bundle.

* Foster, *loc. cit.*, p. 961.

† Bechterew, *loc. cit.*, pp. 96, 97: 'In der Pyramidenbahn sind, wie ich unlängst nachgewissen, zerstreute Fasern eingelagert, welche einer etwas früheren Entwicklungsphase

Considering that the fibres of the 'intermediate' bundle, like those mentioned by Foster, are described by Bechterew as scattered, that, like them, they undergo descending degeneration and coincide with them in position, it is difficult to look on them otherwise than as identical. But Bechterew speaks of the bundle as consisting of fibres which do not degenerate as a consequence of cerebral affections. Foster mentions degeneration on both sides of the cord as the result of cerebral lesions in one hemisphere. Bechterew, on the other hand, speaks of double degeneration on one side only, in the intermediate bundle, that is to say, and in the crossed pyramidal tract, as resulting from severance of the inferior peduncle of the cerebellum. If the latter conditions represent a functional relation between

entstammen. Dieselben gehören einem ganz selbständigen System an; denn bei Degeneration der Pyramidenbahn nach Gehirnaffektionen findet man stets eine Anzahl nicht degenerierter Fasern, die mit jenen älteren Elementen der Pyramidenstränge allem Anscheine nach identisch sind. Sie entsprechen meines Erachtens in allen Stücken dem mittelst der Degenerationen — methode aufgefundenen intermediären System von Löwenthal und können daher mit Recht als intermediäres Bündel zusammengefasst werden. Die in Rede stehenden Fasern haben ihren Ursprung im Kleinhirn und gesellen sich im verlängerten Marke zu den Pyramidenbahnen. Dies erhellt einerseits aus dem Umstande, dass sie proximal von der Brücke nicht mehr angetroffen werden, anderseits zeugt hierfür die Thatsache, dass nach halbseitiger Entfernung des Kleinhirns u. a. absteigende Entartung homolateraler Pyramidenfasern und sogar vorderer Würzelfasern beobachtet ist.' *Marchi Rivista Sperimentale di freniatria*, xiii., 1883.

these two tracts, it is difficult to see why the degeneration should be on both sides of the cord when it is started in the cerebrum instead of the cerebellum, although the absence of degeneration in the fibres of the idiolateral group on the opposite side to the lesion in the hemisphere remarked by Bechterew would agree with the facts as related by Foster. Whatever may be the explanation of these apparently contradictory facts, it is noteworthy that severance of the inferior peduncle or removal of one-half of the cerebellum causes degeneration on the same side in the pyramidal tract and anterior roots of the spinal nerves; for this certainly seems to suggest that the cerebellar system may be concerned, to some extent, in keeping up the nutrition of the larger or cerebral system, and it will be seen later on that this fact does not stand alone.

Of the
funda-
mental
groups.

As to the functions of the fundamental groups of fibres, the anterior and the lateral, very little can be definitely asserted. Some of the fibres of the anterior portion have been traced to the posterior horn and Clarke's column of the opposite side, some to the anterior, and some to the lateral horn of the gray matter. The fibres of both portions are for the most part short, and run up and down the cord in branches or arborescences round motor or other cells.* The

* Bechterew, *loc. cit.*, p. 81. Page 78: 'Weiterhin ist in den Vorderstrang Grundbündeln ein Fasersystem enthalten, welches unter Kreuzung seiner Elemente durch die vordere Kommissur hindurchgeht und in Nervenzellen des Hinterhornes und insbesondere der Klarkeschen Säulen wurzelt.'

greater part of the lateral column has been said to carry impulses to and fro between the local mechanisms below immediately connected with the several spinal nerves and the brain above.* The lateral horn is most conspicuous in the thoracic and lower cervical regions, and it is precisely in this portion of the cord that the lateral columns undergo a decided development, whereas the anterior columns, on the other hand, are greatly diminished. The fundamental lateral column is believed to constitute a path whereby impulses of touch and pain pass up the cord to the brain.†

Although physiologists generally agree that the posterior columns constitute a great path for sensory impulses, yet in this case again, as in that of the fundamental columns, it has been found impossible hitherto to fix with anything like certainty the functions of the various parts of which they are composed. Portions of the median column have been found to correspond to the nerve-roots of the various sections of the cord, the sacral, lumbar, and thoracic occupying a position internal to the cervical. It has also been noticed that severance of the posterior column in animals produced no analgesia.‡ This fact has led to the conclusion that the columns in question are in reality channels for muscular sensibility. There are, however, certain fibres in Goll's column finer than the rest, which, by reason of their more slender calibre,

Of the
posterior
columns.

* Foster, *loc. cit.*, p. 959.

† Bechterew, *loc. cit.*, p. 106.

‡ *Ibid.*

appear to differ in function. Besides the fibres of this column, derived from the posterior roots of the spinal nerves, others are said to join it from the cells in the posterior horn of the gray matter, some of them proceeding from Clarke's column.* The fibres in Burdach's column are for the most part thick.† Although certain fibres of the posterior columns constitute an uninterrupted path for sensory impulses to the medulla oblongata, others, which are very numerous, pass into the gray matter of the cord at various levels,‡ the former being said to be chiefly fine, the latter principally coarse fibres.§ If we admit Bechterew's view that the posterior column carries only impulses of muscular sensibility, we have still to account for the difference in calibre between the two sets of fibres. Moreover, if the impulses of muscular sensibility from the skeletal muscles pass along the posterior column, what may be the path of similar impulses proceeding from the muscular coats of the intestines? In the usual course of things, we are not aware of the movements of these organs, but the conclusion to which this fact leads is that the sensory system is not in this case connected with the cerebrum, the great seat of all sensation. The sensation is unconscious. There seems to be no sufficient reason for denying the existence of muscular sensory impulses depending on cells in the spinal cord. Motion, indeed, is so entirely bound up with sensa-

* Bechterew, *loc. cit.*, p. 37.

† *Ibid.*, p. 60.

‡ *Ibid.*, p. 57.

§ *Ibid.*, p. 58.

tion that the former is inconceivable in the normal state without the latter, and we know very well that the presence and pressure of food in the intestine leads not directly but indirectly—that is to say, through the medium of sensation to the contraction which follows. The latter is evidently of a reflex nature. In view, however, of the involuntary character of intestinal action, it seems natural to connect the nervous mechanism of the causative or sensory impulses—at least, when functioning normally—primarily with the gray matter of the cord, though a secondary connection may exist between the latter and the cerebellum.

With respect to the functions of those fibres which, instead of forming part of the posterior column for any considerable distance, become almost immediately connected with the cells of the posterior horn of the gray matter, we are again reduced to conjecture. Were one to look in this locality for cells corresponding from a sensory point of view to well-nigh each particular kind of cell to be found in the ventral or motor-horn, we should expect the presence of musculo-sensory cells to the skeletal muscles, which we should be inclined to connect with thick or medium-sized fibres rather than with the very fine fibres distributed to this locality; we should, in addition, expect similar cells to be present to supply sensory impulses by which the motor activity of the intestines is brought about, and by which over and above this general movement that of the mucous membrane is caused in the process

Functional
correspon-
dence of
elements
in the two
horns.

of secretion. These, it may be supposed, would be closely allied to, if not identical with, the chemico-sensory cells to which allusion has been made. Further, we should look for some cells connected in at least a secondary manner with the vaso-motor mechanism. These, if there be such, and those which contribute to the action of secretion, we should be disposed to connect with the finer fibres of the nerve-roots, the more so since the connections between the sympathetic system, containing as it does vaso-motor fibres, and the cord are also of relatively very slender calibre. Then, again, if the fibres of the posterior columns, as Bechterew asserts, be not the channel for the conveyance of tactile impulses, we should look for cells constituting an intermediate stage in this process. This physiologist regards the thicker fibres of the posterior roots as being paths of muscular sensibility, the thinner as carrying impulses of cutaneous sensation.* Are we to understand, however, that under this expression cutaneous sensibility (*Haut Sensibilität*) those proceeding from the membranes of the digestive tract are to be included? Many of the finer fibres belonging to the lateral bundle of the posterior root pass, as already stated, to the very centre of the gray matter between the anterior and posterior horns,† where they lie in close proximity to the group of small cells at the base of the anterior horn, and not far removed from that portion of the lateral horn which Gaskell regards as being connected with the involuntary

* Bechterew, *loc. cit.*, p. 43.

† *Ibid.*, p. 38.

muscle of the intestines. It certainly seems as though the fine fibres of the motor or ventral root and those of the sensory or dorsal root were distributed to cells lying very close to one another.* Near to them also is the important group of large cells called Clarke's column, which, although receiving thick fibres from the posterior root, is not on that account necessarily directly connected with muscular sensibility.†

The thickness of the fibres and the size of the cells are, as before remarked, factors which cannot be overlooked. The two usually go together, and betoken the generation and conveyance of impulses of a certain and, indeed, of a proportionate degree of force. But where are we to look amongst the various forms of nervous action for one which could be said to correspond to the cells of Clarke's column in this respect? It will be remembered that these cells have been described as large and fusiform, and as being embedded in fine fibres. This interlacing of fibres, so as to surround a nerve-cell with which they come in contact without being in absolute continuity, is a noteworthy but not exceptional feature of the nervous system. To a greater or less extent it obtains in many regions. When, however, the fibres are espe-

Size of nerve-cells and thickness of fibres as a criterion of function.

* Bechterew, *loc. cit.*, p. 44.

† Foster, *loc. cit.*, p. 958: 'It seems natural to infer that the cells forming this vesicular cylinder are connected neither with the ordinary somatic motor fibres governing the skeletal muscles nor with the ordinary afferent sensory somatic fibres coming from the skin and elsewhere, but in some way with some special sets of fibres.'

cially numerous, as they are in this instance—and as they are in, perhaps, an even more marked degree in the cerebellum—when they, so to speak, envelop the cell, as in Clarke's column and in the case of Purkinje's giant cerebellar cells—there is evidently a special meaning in this mode of distribution. The large cells thus enwrapped occupy a central position : they must perform a central function. When they vibrate, the intensity of vibration of all the smaller cells connected with them is suddenly increased. The conditions which we have before us do not admit of any other interpretation. The large cell may send forth its impulse along its main fibre or axon, but as soon as it becomes active the smaller cells with which it is connected must necessarily vibrate more powerfully than before. It matters not, indeed, whether the fibres connecting the latter with the former are afferent or efferent channels, for in the one case the large cell would, one might suppose, act as an attractive centre, whilst in the other event its action might be of a radiating or propulsive kind. To the large cells, therefore, on account of their relations to the smaller ones, we are justified in giving the title 'increase of impulse' cells.

Increase
of impulse
cells.

One of the primary conditions of organic life is that functional activity is never equal throughout the whole organism. It varies as to place, as to time, and as to degree or intensity. This condition is so universal, and so essentially a part of our nature as that of every other living creature, that we are somewhat

inclined to overlook its consequences. Yet it is undoubtedly a fact that our nervous system must be fashioned so as to conform to this variability, which is, as it were, the pivot on which it turns; and were it possible to create and build up a complicated organism like our own, it would be incomplete, and it would not function properly unless full and satisfactory provision were made for the sudden and forcible transference of its activity now into one part and now into another. Within certain limits, the more powerful such transference is, the more intense, one may say, will the vital force of the organism be.

As long as breath comes and goes in the body, even in a state of the most perfect repose, the whole may be said to be undergoing a process of oxidation; but when passing from the condition of rest certain parts become functionally active, oxidation in them is rendered very much more intense. In this sudden augmentation of activity three nervous factors come into play. The first of these is of a sensory, or, it may be, of a sensory-motor, nature (sensation leading to motion); the second is a vaso-motor one; the third, intermediate between the other two, an increase of impulse factor. Both psychologists and physiologists agree that the sensory factor is always the primary one. You cannot will a sensation until you feel it; you cannot intensify the action of cells representing a feeling or a thought until they have begun to vibrate. Sensory impulses vary very much in the degree of their intensity. We may hear a deafening crash, as

The nervous factors in the local augmentation of activity in an organism.

we may catch a distant echo. We may see a dazzling light, or we may observe a faint ray or glimmer, and the result in one case differs very much from that in the other. But, nevertheless, one sensory impulse cannot, or can only to a very slight extent, act directly as an augmenting influence on other sensory cells. The augmentation must always, under normal conditions, take place in a reflex manner, through the 'increase of impulse centre,' that is to say, and through the vaso-motor centre. The loudest noise will frequently lead to no other effect than a temporary increase in the vibrations of the purely auditory cells. On the other hand, a whisper in the dark may make one tremble with anxiety. It is plain, therefore, that the effect of a sensory stimulus does not depend on its intrinsic force, but on the conditions under which the reflex stimulation is brought about. When, however, many groups of sensory cells—groups representing feeling as well as sensation pure and simple—are all vibrating together, the cells on which the reflex depends are stimulated in a far higher degree, and the general effect is proportionately greater. That produced by cells representing the feelings is always more intense, and especially reacts upon the heart; but what the cause of this may be, whether such cells are more numerous or whether they receive a greater supply of blood, no one has as yet been able to determine.* That the intensity of sensation and of the

Increase
in the
sensory
stimulus is
chiefly due
to internal
causes.

* It seems not improbable that our emotions are in reality due, not to the action of separate 'emotional' cells, but to the

reflex by which it is brought about does not depend on the perfect functioning of the peripheral sense-organ is strikingly proved in the case of Beethoven; for his symphonies, which constitute in the whole realm of human production one of the most prominent examples of intense cerebral action, were composed after he had become a sufferer from deafness. This shows that the main factor in the increase of sensation, taken in its widest meaning, is an internal one, and enables us to disregard to a great extent external influences.

As it is, therefore, evident that all intensification of sensation is due in the main to an internal cause, it is necessary to inquire further into the nature of it. It is a common thing to say of a person who has solved some very difficult problem, he has worked it out by an effort of 'will.' This means, if it have any physio-

The physiological mechanism of will.

mode of vibration of the ordinary sensory cells in which vaso-motor activity plays a very important part. Thus, a condition of relaxation or of too great expansion of the tissues, including the nerve-cells, is a fertile cause of melancholy, and can often be at once removed by the use of such a drug as strychnine, which stimulates contraction. We see the fruits of this relaxation and melancholy in the increase in the number of suicides which invariably takes place when the summer heat becomes very oppressive. The actual cause of the melancholy and relaxation is probably to be attributed to a weakening of the heart's action and a general diminution of blood-pressure and hence of oxidation. A sudden change from cold or cool to very hot weather seems to affect the nerve-centres in an especial manner. Irritability and excitability may also be traced in a great measure to causes connected with the vascular system and the manner in which the processes of oxidation are carried out.

logical meaning, that in addition to the purely sensory or intellectual cells others of a different type, which we may call for the moment 'will' cells, have been brought into play. But it will be clear to everyone that 'will' cells in this sense must be 'increase of impulse' cells. They must, that is to say, possess certain attributes or properties which enable them to intensify the action of other cells, either greater size and more elaborate branches, or a greater supply of blood, or something of an analogous nature, by means of which a sufficiency of force may be generated to augment the action of the sensory cells. It has probably never been suggested that the 'will' centre is identical with the vaso-motor centre; yet the supposition, though probably not true, is nearer to the truth than one might be led at first sight to believe. The 'increase of impulse' or 'will' cells act, one may expect, both indirectly on the sensory cells through the vaso-motor cells and directly also. The reflex—for will is certainly a reflex—may be described thus: Action is started in the sensory or intellectual cells of the cerebral cortex; it causes the 'increase of impulse' or 'will' cells to vibrate; these react on them, and at the same time transmit a decided stimulus to the vaso-motor centre. The result is a quickening or intensification of the whole process of thought or sensation.

The part
of the 'in-
crease of
impulse'
cells in in-
voluntary
action.

The word 'will,' however, is often used in a way which, physiologically speaking, is not correct, or, at least, is very liable to cause error.

There are two elements in volition—a sensory or intellectual element, and an increase of impulse; but the term ‘will’ is employed in a vague manner to cover or express both elements. We should have a very much clearer conception of things as they are if we were to keep the two elements separate. We call the action of the ‘increase of impulse’ cells ‘will’ when they act in conjunction with the sensory and intellectual cells of the cerebral cortex, but there is no reason whatever to suppose that they do not play a part—an essential and necessary part—in involuntary action also. How, then, are we to designate the ‘increase of impulse’ cells under these circumstances, if our only term for them is ‘will’ cells?

Doubtless it is true that we have a still further ^{The nature of} conception of voluntary action—a conception, be it ^{desire.} said, which corresponds to certain physiological conditions, but not to any specific class of nerve-cells. When we have a desire or longing, however ardent it may be, the only cells to the action of which we can attribute it are, in the first place, the sensory cells of the cerebral cortex, representing the idea and the emotions connected with it other than will, assuming that the cerebral cortex is the seat of the emotions; and, in the second place, the ‘increase of impulse’ cells, already mentioned, together with the sensory and vaso-motor cells immediately depending on them. These ‘increase of impulse’ cells are not, however, to be found in the cerebral cortex, where, beyond the cells already mentioned—that is

to say, the ordinary sensory cells—there are, probably, none specifically representing desire or volition.

‘But,’ someone will perhaps remark, ‘I may have the idea of an act without executing it, or I may hesitate before performing it; yet when I do accomplish it some new factor comes into play, and that factor is ‘will.’ In psychological phraseology such a statement may be correct. Let us examine it physiologically. If the sensory cells of the cerebral cortex alone are stimulated either feebly or violently, we have the idea or the sensation only; but if, on the other hand, a connection is established with the ‘increase of impulse’ cells and with the motor cells of the cerebral cortex, then, in addition, we have action. Hesitation is due to the stimulation of the ‘increase of impulse’ cells by two groups of sensory cells, representing two distinct ideas. The factor on which the existence of a connection between the sensory and ‘increase of impulse’ elements depends is association or habit. In some, however, the readiness with which the ‘increase of impulse’ cells respond to stimulation is far greater than in others, and such persons are inclined to be wilful and to have exaggerated views and feelings and reactions. But any philosophy which is based on the supposition that, in addition to the ‘increase of impulse’ cells, there are other ‘will’ cells, or that we have any means of acting in opposition to the strongest stimulus, is mere fancy. It lies with us, therefore, to so order our lives and to so excite our nerve-cells

that the strongest stimulus is that which is best for us and for others. If we do so, we shall have no cause either to deplore the fact that volition is a matter of habit and of reflex action, or to regret having based our moral efforts on a physiological foundation.

Amongst the many kinds of cells belonging to the nervous system, are there any, we may now ask, the characteristics of which correspond at all to those one might expect in cells destined to intensify the action of other cells? We have already drawn attention to the cells of Clarke's column, and it is natural to connect these with the giant cells of Purkinje in the cerebellum, firstly, because the axons or main fibres of the former lead to that organ; secondly, because both sets are imbedded in fibres; and, thirdly, because, though very large, neither set is motor nor sensory in the ordinary acceptation of the term.

In order to follow this argument to its logical conclusion, it is now necessary to consider somewhat in detail the whole question of the functions of the cerebellum. Current opinions with reference to that organ may be divided into two categories: there are those who look on the cerebellum as a reinforcing organ to other parts of the nervous system—as a reservoir of force, which may be drawn upon to a greater or less extent, according to the degree of each local or temporary need; whilst others see in it nothing more than a great co-ordinating centre, a great junction, that is to say, where one part of

Points of resemblance between the cells of Purkinje and those of Clarke's column.

Opposite views respecting the functions of the cerebellum.

the nervous system is brought into connection with another. These views, the latter of which is now almost universally held, are not in reality so antagonistic or divergent as they might appear to be. If the cerebellum acts as a reinforcing organ to other parts of the nervous system, its anatomical relations, being, as is well known, extremely elaborate, would naturally imply a very considerable amount of co-ordination as an essential element in its activity. Under pathological conditions the absence of this factor would make itself felt at times, and especially immediately after an operation, in a somewhat marked manner. If, on the other hand, the cerebellum be a great co-ordinating centre, it could only be said to exert no reinforcing or augmenting influence on the cells with which it is connected anatomically, provided the cerebellar cells be of the same size and power as those on which they react. This, however, we know is not the case, for the cells of Purkinje are beyond all question amongst the largest and most powerful nerve-cells in the whole body;* and to contend that, under these circumstances, they do not, when sufficiently stimulated, increase the force of the action of other cells seems to be the very negation of both fact and reason.

Patho-
logical
evidence.

Although pathological evidence as bearing on the function of any part of the nervous system must always be received with a certain degree of caution,

* The diameter of these cells is said to be $\frac{1}{1000}$ to $\frac{1}{800}$ of an inch.—Quain's 'Anatomy,' p. 313.

because of the very complicated nature of the mechanism we have to deal with, yet a thorough consideration of the following cases will materially help to establish the truth of the above statements.

‘When* in an animal—monkey, cat, or dog, for instance,’ says Foster—‘the whole cerebellum is removed, and the immediate effects of the operation have passed away, the condition of the animal is such as to excite wonder that the loss of so large and apparently important an organ has brought about so little change. Its psychical powers do not appear to be at all impaired or changed; it is as alert and intelligent as before. Sight, hearing, and the other special senses seem unaffected. There are no distinct signs of its cutaneous or general sensibility being deficient or altered. The most that can be observed is a deficiency in its movements; these are marked by a certain amount of what we may for the present speak of under the general term of “inco-ordination.”’

The same author then relates the results of the removal of one-half of the cerebellum. This operation leads to no change in the psychical condition nor in the development of sensations, but to an abnormal state of the motor mechanism. If the right half of the organ be removed, ‘the animal uses the left side, and especially the left limbs, more than the right’; it leans and falls to the right side, and ‘shows by the character of its movements that the muscles of the right side are not being worked in a normal manner.’

* Foster, *loc. cit.*, p. 1206.

‘The condition is one not so much of absolute loss of power as of imperfect action.’ ‘The imperfect action has been described under the general term “inco-ordination,” but has been analyzed, though all observers are not agreed in this, on the one hand into diminished power—that is to say, energy of contraction (parasthenia), which in the dog is most conspicuous in the muscles of the hind-leg—and on the other hand into a diminished tone (paratonia) and an unsteadiness of contraction due to the occurrence of small and rapid though regular tremors (parastasia).’ ‘Obviously,’ he continues, ‘there is something wrong in the nervous machinery for carrying out the movements, and especially perhaps the voluntary movements of the right side.’*

‘Disease† of the cerebellum, uncomplicated by lesions in other parts of the brain, in no way interferes with psychical powers, and does not in the least impair sensations, either special or general, but it does interfere with the action of the skeletal muscles. The disorder which it brings about—an unsteady gait, the “cerebellar reel,” not wholly unlike that of drunkenness—is usually described as “inco-ordination,” but so far as it can be analyzed seems to be of the same nature as that produced experimentally in animals—the same diminution of power leading to a difficulty in maintaining the erect posture, the same diminution of tone and the same occurrence of tremors have been observed.’

* Foster, *loc. cit.*, p. 1207.

† *Ibid.*, p. 1208.

Dealing with this question, Ferrier relates many interesting facts, amongst which the following are some of the most noteworthy :*

Ferrier's facts.

Flourens showed that recovery, even after deep incisions into the substance of the cerebellum, was a common occurrence, although complete removal of the organ in birds was never followed by such favourable results. In the latter case, whilst life may be prolonged for several months, the symptoms of cerebellar lesion are always present.†

Sixteen days after Dalton had destroyed two-thirds of the cerebellum of a pigeon he only noticed a general debility and a slight difficulty in recovering itself when it had alighted from flight.‡

Wagner observed complete recovery in a pigeon which lived for twelve weeks after the removal of more than half of the cerebellum.

When, however, the corpora dentata were affected, complete recovery did not follow.§

Still more interesting is a case reported by Luciani, in which a dog is said to have survived the almost complete removal of the cerebellum for eight months. The remainder of the life of the animal has been divided by that physiologist into three periods. The symptoms during the first of these consisted in inflammatory complications, spasms, and an excessive weakening of the motor mechanism. These he attributed entirely to the effects of the operation and

Luciani's cases.

* Ferrier, 'The Functions of the Brain,' pp. 174-219.

† *Ibid.*, p. 177. ‡ *Ibid.*, p. 177. § *Ibid.*, p. 177.

to the presence of an open, suppurating wound. During the second period a general amelioration of the state of the animal took place, although weakness and unsteadiness of gait remained. This shows that the weakening of the motor mechanism was not solely due to the suppuration of the wound. Luciani concluded that the cerebellar ataxy was caused by the imperfect tone and insufficient energy at the disposal of the nervous system governing the muscles essential to animal life (*il sistema nervoso motore dei muscoli della vita animale*).^{*} The third period, embracing about two and a half to three months, is characterized by Luciani as one of progressive and rapid general malnutrition (*progressiva e rapida denutrizione generale*).[†] The weight of the animal had fallen from 5,090 gr. at the beginning to 3,040 gr. at the time of death, when it was suffering, in addition, from purulent otitis, catarrhal conjunctivitis, and affections of the joints. Ferrier, who is opposed to the view that the cerebellum has anything to do with the nutritive forces of the body, attributes the impaired nutrition and death of the animal to the special diseases above-mentioned. Luciani, on the other hand, is inclined to regard these as definite symptoms of malnutrition, due to the loss of an organ intimately concerned in keeping up the nutrition of the body.[‡] It would be interesting to know whether after the

* Luciani, 'Lince Generali della Fisiologia del Cerveletto,' p. 24.

† *Ibid.*, p. 25.

‡ *Ibid.*, p. 26.

removal of the cerebellum there is any loss of power in the heart corresponding to that so clearly marked in the case of the voluntary muscles.

In another case* the cerebellum of a bitch was completely removed. Four months after the operation the animal gave signs of 'heat,' was impregnated, and 'was allowed to survive until she had whelped, nearly a year after.' Parturition was regular and the maternal instincts normal. The general health of the animal was good, and she had increased in weight. A small fragment of the right lobe of the cerebellum alone remained after death, which was caused by the administration of chloroform. The motor mechanism was more seriously affected than in the previous cases, the animal being only able to move by 'butting forward,' but there were few, if any, signs of inflammation.

It will probably be admitted that the evidence in the first case is distinctly more favourable to Luciani's view than to that of Ferrier. As regards the second case, there is, perhaps, more room for doubt. It is true, on the one hand, that the nutritive condition of the animal was good, that it had even improved, and Ferrier assumes at once on the strength of this fact that the evidence of malnutrition in the first case may be entirely disregarded. With respect to this, however, certain matters deserve further consideration. We have spoken of the cerebellum as a centre for the increase of impulses, but are we sure that it is the

* Ferrier, *loc. cit.*, p. 179.

only centre of that kind in the body? Is it not highly probable that Clarke's column, which, as we know, is connected with it anatomically, is a secondary centre of the same order?

It has been ascertained that one portion of the cerebellum may replace functionally other parts which have been removed, and is it not, therefore, possible that one part of the cerebellar system may replace to some extent the cerebellum itself?

For many women—and this may apply to animals also—the period of gestation is one which is distinctly favourable to the nutritive processes of the body. They gain in flesh and in weight, as many can doubtless certify from personal observation. The heart especially undergoes a remarkable increase in size and power.

The state of the animal in this respect may therefore be held to account for its good condition, and to have counterbalanced any unfavourable influence which would otherwise have made itself felt owing to the excision of the cerebellum. But though the building up process, as regards the whelps, seems in this case to have run its course, and though the animal's system appears to have been favourably affected by it, there is one point with regard to which the evidence is by no means clear. 'The animal,' Ferrier remarks, 'having been impregnated four months after complete extirpation of the cerebellum, was allowed to survive until she had whelped, nearly a year after.' Putting the most natural construction

on this statement, one would be inclined to suppose that the period of gestation, instead of being as usual 62 or 63 days,* had been so prolonged as to extend to many months. In the article to which Ferrier refers one in connection with this matter† there is the same obscurity in regard to this point, for no direct mention of the duration of the period of gestation is made. It is said, however, that it began about the beginning of September, and at the meeting of a scientific society interested in the case it was resolved that the animal should be allowed to survive until after she had whelped. She was again examined by the members of this society in the following April—that is to say, about four or five months after whelping—supposing the period of gestation to have been of normal duration. It is to be regretted that on this point clear evidence is not forthcoming. But if we suppose the period of gestation in this case to have been normal, the main factors in this problem would remain unchanged, for we are justified in assuming that the nervous system as a whole controls nutrition; that the cerebellar system (of which the cerebellum, be it said, is only a part) exercises an especially powerful influence in this respect by reason of the large cells which it contains and of the connections of these cells with the rest of the nervous system; and that nutrition is frequently so modified during the period of gestation that even the removal of the cerebellum may not lead

* Miles, 'Stock Breeding,' p. 406.

† *The Alienist and Neurologist*, St. Louis, July, 1885.

to the results which would otherwise follow. In dealing with this subject it is, however, very necessary to guard against drawing conclusions of too absolute a nature. Although the nervous system undoubtedly controls nutrition, yet absorption in the stomach can still take place when all or nearly all the nerves of that organ have been cut. If, then, this occurs when the direct nervous supply of the part in question has been interrupted, it is not surprising that the nutritive processes in general should, under favourable conditions, go on for a time in a more or less satisfactory manner after the removal of the cerebellum; for the action of this organ, though very powerful under appropriate stimulation, is nevertheless always indirect. It does not influence the tissues directly, but only through the rest of the nervous system. It is essentially a reinforcing organ, and if it appears to be specially connected with the muscular system, it is because all movements require an energetic discharge of nervous force, the variations of oxidation by which they are produced being also of an intense nature. At the same time, the cerebellar system must inevitably react upon all parts of the nervous system with which it is directly connected, and in this way on the tissues corresponding to them.

Cases of defective development of the cerebellum.

After having pointed out that cerebellar lesions in man, especially if extending to the whole organ, are usually attended by disturbances of equilibrium, Ferrier proceeds to cite two interesting cases of defective development of the cerebellum, the one being an

instance of complete atrophy, whilst in the other that organ was represented by a very small portion of the right lobe only. Alexandrine Labrosse lived to the age of eleven years. After death, in the place of her cerebellum nothing but a cyst containing serum was found. She is described as being physically well developed and as possessing normal sensory powers. On the other hand, she was defective in intelligence, could not articulate distinctly, could not stand until she was five years old, and at the age of seven had difficulty in holding herself upright, and often fell. The other case was that of a girl who died of phthisis at the age of fifteen. She resembled Labrosse in regard to her sensory faculties and defective articulation, besides being somewhat weak in intellect, although not pronouncedly so. Her muscles were weak, but she could walk 'well and steadily.' The early death in both these cases, and in one of them the susceptibility to phthisis, may be looked on as suggesting a lack of vitality or nutritive power.

According to Ferrier, the doctrine of Flourens, that the cerebellum is indispensable to co-ordination, is untenable, for in that case the girl Alexandrine Labrosse would have been totally incapable of walking. Of this there can be no doubt, and it seems very manifest that if the cerebellum is a co-ordinating centre this function is of a secondary character. Nor is it possible to accept Ferrier's suggestion that its function is primarily to act as an organ of equilibration, unless we give to that term a much more

Co-ordination is possible in the absence of the cerebellum.

extended meaning than it usually possesses. If we do not, how are we to explain the malnutrition and the loss of muscular power and tone which in a more or less pronounced form are fairly constant and sometimes very marked symptoms after extirpation has taken place? Let us but look at the cerebellum as an organ, the primary function of which is to increase impulses of all sorts, but especially those in which chemical action is intense, and all our difficulties will fade away and vanish. Little by little we shall be able to evolve a conception of that organ in which the co-ordinating, the equilibrium controlling, and the nutritive aspect of its functions will entirely harmonize with one another; we shall, indeed, see that these various factors are absolutely essential and complementary. We have but to bear in mind a few very simple truths: firstly, that no marked increase of impulse can occur without an increase in the chemical constituents out of which it is generated; that is to say, you cannot obtain increased nervous action, and, above all, prolonged nervous action, without an increase in the blood-supply to the parts affected; secondly, that every increase of impulse implies directly or indirectly an increase of chemical action; and, thirdly, that all voluntary action implies an increase of impulse, for, as we have already shown, an effect of will is but the result of the cerebellar and other 'increase of impulse' cells acting in combination with the sensory or sensory and motor cells of the cerebral cortex. Since, moreover, maintaining one's

equilibrium is an essentially voluntary act, it follows that the nervous mechanism by which it is carried out must of necessity contain voluntary elements. These, as Foster remarks* in the above passage, are those which are chiefly lacking after the removal of the cerebellum. We are, however, so much accustomed to the sensory and the 'increase of impulse' elements in voluntary action that the liability to error in this matter is very great.

It has, moreover, been pointed out that, although the cerebellum undoubtedly contains cells, the property of which, by reason of their size, must be to increase the impulse of other cells, there are probably others similar in function, though weaker in the degree of the force they generate, to be found in the spinal cord, as, for instance, in Clarke's column. The existence of secondary 'increase of impulse' centres seems, indeed, not one whit less natural than of secondary sensory or motor centres, and all may probably be said to depend on the fact that the nervous system is the result of fusion of separate elements. The possible existence of several collections of 'increase of impulse' or reinforcing cells is a factor of great importance, and one which on many occasions has been entirely overlooked. It gains some support, moreover, from the fact that the lower you descend in the animal scale, the less perceptible are the evil results of extirpation of the cerebellum. There does, therefore, appear to be some ground for

Secondary centres of the cerebellar system.

* Quotation, p. 122.

supposing that when the cerebellum is removed, other allied centres may perform for a time the functions devolving previously upon it, thus enabling the creature to prolong its existence under conditions of diminished vitality.

It is often said that the removal of the cerebellum leads to no diminution in the psychical powers, and this statement, presumably, applies to animals. As bearing on this point, it is necessary to recall the fact, already mentioned, that sensation is to a considerable extent independent of the will. It should also be remembered that in the two cases of defective development of the cerebellum the intellectual powers were decidedly affected.

The factors
in equili-
bration.

But in what way is it supposed that the cerebellum produces effects of equilibration, unless it be by reinforcing and increasing the ordinary muscular, sensory, and motor impulses? Does anyone imagine that the cerebellum is a special sense organ, having functions similar to those of the semicircular canals? There does not appear to be any ground for such a supposition. No one, we fancy, has ever spoken of the cells of Purkinje as sensory cells in that sense. What, then, are the factors in equilibration? Muscular sensations and ocular impressions and others proceeding from the semicircular canals tell us, let us say, that we are falling. We recognise the need of reaction, and, guided by our sensations or impressions of the kinds enumerated, and by others, it may be, coming from the soles of our feet and skin,

we recover our balance by a violent muscular contraction. What part in all this does the cerebellum play, unless it be that of increasing the motor impulse, to the group of muscles set in motion? or, if we put it otherwise, what factor is wanting to complete the process?

In the cerebellum there are three main elements—The anatomical elements in equilibration. the cells of the rust-coloured layer, those of the molecular layer, and Purkinje's cells. What are the functions of these, and in what way did they contribute to the recovery of our balance? Was there any sensory element in the sequence of nervous acts which could not be accounted for by referring it to the cerebrum? Let us suppose that the sensory elements alluded to above were reduplicated in the cerebellum: for what purpose would such a reduplication take place unless it were to borrow force from the great cells of Purkinje?

That it could not be for the sake of bringing about co-ordination pure and simple is evident, for we have co-ordination in the absence of the cerebellum.*

The will as a factor in this problem is one of such importance that further inquiry into the part which it plays in equilibration is necessary. We have already

* Ferrier, *loc. cit.*, p. 181: 'If the cerebellum were indispensable, according to the doctrines of Flourens, for the co-ordination of movements, it would be impossible to harmonize the actual facts of clinical observation with an hypothesis so formulated; for it should have been impossible for Alexandrine Labrosse to walk at all if the co-ordinated movements of locomotion were dependent on the cerebellum.'

shown that the will, as we frequently use the term, must consist of two very different elements, viz., a sensory element, which may take the form of sensation of a primary kind, or may be so complicated as to represent an idea or group of sensations, but which in all cases of *conscious* action is connected with—nay, is generated in—the cerebral cortex, and in addition to this an element by means of which sensation and nutrition—that is to say, chemical action—are both intensified. The seat of this second element is generally supposed to be the cerebral cortex also, and this has so happened because we are always apt to connect will with consciousness. But natural as this connection may be, it by no means implies community of origin; and a histological examination of the cortex reveals the presence of no cells (if we exclude motor cells), to which, as in the case of the cerebellar cells of Purkinje, we should be justified, by reason of their size and relations, in attributing a power to increase the impulse of other cells. And since, moreover, vaso-motor changes are an essential accompaniment of all forms of activity throughout the body, we should expect to find a more or less close relationship between the ‘increase of impulse’ cells and the vaso-motor mechanism, and that this does really exist seems the more probable owing to the proximity and relation of the cerebellum to the medulla oblongata, the seat of the chief vaso-motor centre. A curious feature of the cerebellum is the colouration of the rust-coloured layer. Is this due to

The cerebellum in voluntary action.

pigment, it may be asked, or to a more plentiful supply of blood than goes to other parts of the organ? One is also naturally led to connect this matter with the colouration of the red nucleus, which is in very close anatomical relationship to the cerebellum.

Ferrier asserts that the mechanism of cerebellar co-ordination is essentially independent of consciousness and volition, a statement which, seeing that voluntary muscular action is almost invariably one of the chief factors in it, sounds at first rather like a contradiction in terms. He contends that in many animals you may abolish both consciousness and volition by removing the cerebral hemispheres, and still leave the mechanism of equilibration intact. But it is evident that if the sensory element is to be found in the cerebral cortex, removal of the latter or of the greater part of the hemispheres would leave a most essential part of the mechanism of volition untouched.

That one-half of the cerebellum should correspond to one-half of the body—nay, more, that individual parts of each half should bear a functional relationship to certain groups or sets of muscles, or even to certain movements—is perfectly natural and in accordance with the ‘increase of impulse’ theory of cerebellar functions. It also agrees with the fact that when lesions as nearly as possible symmetrical are produced on both sides of the cerebellum, the amount of disturbance of the equilibrium is very slight. This,

The relationship between parts of the cerebellum and groups of muscles.

indeed, if taken alone, should be enough to convince anyone who analyzes the phenomena that the cerebellum must of necessity contribute a very great amount of force to the muscular system ; otherwise, it may be said, the removal of one-half would not lead to the spasmodic contractions on one side or in one direction which are known to occur.

Anatomical
relations of
the cere-
bellum.

The anatomical relations of the cerebellum may now be briefly considered. It has been described as a great junction between the cerebral hemispheres on the one hand and the spinal cord and spinal nerves on the other, and it will be seen as we proceed that there are considerable reasons for believing it to be connected with every part of the nervous system, and so with every part of the body.

The cerebellum is connected with the rest of the nervous system by three pairs of peduncles, the superior, middle, and inferior. The first-mentioned take their origin in the nucleus dentatus, in a small collection of nerve-cells close to it, and in the superficial gray matter. They leave the cerebellum in front and to the median side of the restiform body, and, forming the boundary of the fourth ventricle, pass forward towards the corpora quadrigemina ; converging and sinking ventrally beneath these they decussate, and finally end in the red nuclei. Some of the fibres pass by or through these nuclei, and end elsewhere. Each of the superior peduncles, however, through the medium of the red nucleus or in other ways, forms a connection with the cortex of the

opposite hemisphere.* This connection is supposed to be of a double nature, permitting the carrying of impulses in both directions. The antero-lateral ascending column also contributes fibres to the superior peduncle, which pass into the cerebellum.

The cerebellar ending of the fibres of the middle peduncles has been traced in the whole of the cortex of both lobes, and also in the median portion, or vermis. Thence they sweep down into the pons, crossing to the opposite side, and in this case also conduction is supposed to be in both directions. Bechterew† divides the fibres of the middle peduncle into two bundles, a cerebral one and a spinal one, the former of which takes its course to the upper portion of the pons, where it becomes connected with the fibres passing down from the cerebral hemisphere of the opposite side. The spinal bundle breaks up into two portions, one passing to the same, the other to the opposite side of the pons. Through the latter the cerebellum is connected with the reticular formation, and with the antero-lateral fundamental bundle of the cord.‡

The connections of the inferior peduncles of the cerebellum with the medulla oblongata and spinal cord are numerous and important. Foremost amongst them is that with the direct cerebellar tract through the restiform body, which goes to form the great bulk of the inferior peduncles. It is thus that, as before

Relations
of the cere-
bellum to
the spinal
cord.

* Foster, *loc. cit.*, p. 1210.

† Bechterew, *loc. cit.*, pp. 394-396.

‡ *Ibid.*, p. 395.

remarked, the cerebellum becomes linked in a direct manner with Clarke's column or the vesicular cylinder. There is a second notable connection with the cuneate and gracile nuclei, and through them with the posterior columns of the cord.* Some fibres from Burdach's column are described as reaching the cerebellum through the restiform body.† Many fibres from the inferior peduncle pass to the inferior olive, both on the same side and on the opposite side.‡ This path is said to be a centrifugal one, and to be composed chiefly of axons of Purkinje's cells, although some fibres also carry centrifugal impulses. Further, there is a connection with the superior olive, partly through the trapezium and partly direct, a possible link between the cerebellum and the vaso-motor centre. By means of the so-called intermediate bundle a centrifugal path is formed to the pyramidal fibres, reaching far down the cord. Bechterew also describes connections between the cerebellum by the central portion of the inferior peduncle and the nuclei of the auditory, glosso-pharyngeal, pneumogastric, and fifth nerve; whilst Foster says: 'Probably a path to the cerebellum is present for impulses flowing inwards along the sensory fibres of the cranial nerves also—that is, of the cranial nerves generally.' That the cerebellum is functionally connected with the third, fourth, and sixth nerves is apparent, since when stimulation is applied it leads to movements of

* Foster, *loc. cit.*, p. 1208.

† Bechterew, *loc. cit.*, p. 387.

‡ *Ibid.*, p. 385.

the eyes, whilst corresponding results follow in the case of stimulation of those parts of the organ connected with the spinal accessory, facial and hypoglossal nerves.

Bechterew has classified the fibres of the spinal cord and medulla oblongata connected with the cerebellum according to the direction in which it is supposed that the impulses travel. As centripetal he regards the posterior column, the direct cerebellar tract, the cerebellar olive tract, and the ascending antero-lateral tract; as centrifugal he designates the cerebellar, superior olive tract, the fasciculus longitudinalis dorsalis, the fasciculus antero-marginalis, the fasciculus intermedius, and a part of the cerebellar olive fibres.

Bechterew's classification.

It will be seen from the evidence already set forth that the cerebellum is connected either directly or indirectly with every part of the nervous system, and that it is thus most favourably placed to act as a general reinforcing centre for nutritive and functional purposes.

It has been related how, with respect to one of the two dogs operated on by Luciani, the loss of the cerebellum was followed in the one case by marked signs of malnutrition, ending eventually in death from that cause. We have considered the cases of two girls, the one totally lacking a cerebellum the other with but a rudimentary fragment, both of whom showed many signs of weakness, and succumbed to an early death. We have numerous instances of removal

Brief summary of the pathological evidence.

of that organ from various animals, but not one of which it can be said that the vital powers were not lowered, nor which terminated otherwise than fatally within a relatively brief period. Experimental investigation also shows that when one-half of the cerebellum is removed, the pyramidal tract on the same side, and with it the anterior roots of the spinal nerves, degenerate.*

Develop-
ment of
the cere-
bellum.

The mode of growth of the cerebellum also throws some light upon its functions. In the infant it is relatively very small, its weight being, according to the computation of some authorities, only one-twentieth of that of the cerebrum, whilst in the adult it is about one-eighth. The proportion the two organs bear to one another is not the same in the two sexes; in the male it is as 1 is to $8\frac{1}{7}$, in the female as 1 is to $8\frac{1}{4}$. We cannot decide from these figures whether the cerebellum is greater in the female or the cerebrum smaller, but there is authority for the statement that the increase in size of the cerebellum after the fourteenth year is greater in the female than in the male.† Why should this be so? Does it not correspond, coming as it does at the age of puberty, with the fact that a greater demand may from that time be made on the metabolic or building-up powers of the weaker sex? How also, one may ask, could the activity of the womb in pregnancy react in so marked a manner as is the case on the development

* Bechterew, *loc. cit.*, p. 96.

† Gray's 'Anatomy,' p. 728.

of the heart, and sometimes of the tissues in general, unless it be through the medium of the nervous control to which these factors are subjected in common?

Returning to the muscular portion of the mechanism of equilibration, we meet with fresh evidence, if rightly read, of the nutritive function of the cerebellum. Full of meaning in this respect are the words of an eminent French physiologist.* 'Like all the organic properties,' he says, 'contractibility has nutrition for necessary basis. It cannot be accomplished without influencing the double assimilation and disassimilation indispensable to the maintenance of the life of the muscular tissue. Every contraction corresponds to a more energetic oxidation, to a more active assimilation, to the formation and the elimination of disassimilated products. The result is manifested immediately in the vertebrates by changes in the colour, the composition, and the temperature of the blood which comes from it, which is almost as rutilant as the fresh and oxygenated blood brought by the artery. The phenomenon is more marked still in the case of paralysis, in certain maladies which produce muscular atony in syncope. The explanation is that muscle, in its state of rest, is at its minimum of consumption, of life, of contraction; it absorbs nothing more than is strictly necessary to its maintenance.

The chemical or nutritive influence of the cerebellum in equilibration.

On the other hand, when the muscle contracts, it wears itself, it expends itself, it absorbs and eliminates

* Letourneau, 'Biology,' pp. 354, 355 (translation).

more. Hence the venous blood which comes forth from it becomes immediately black.

We know that this change of colouration is the indication of important chemical mutations. Thus the venous muscular blood which, in the state of repose, contains only 6.75 per cent. of carbonic acid more than the arterial blood, contains 10.79 per cent. after the contraction.

From the above remarks it will be seen that the functional activity of muscles is indissolubly linked to an increase of nutritive activity—to a higher degree, that is to say, of chemical change. If, therefore, we are justified in connecting the cerebellum with the contractile portion of muscular activity, as we certainly are if we regard it as an organ of equilibration, can we logically put aside the chemical portion of it and say, To this the connection does not apply? The matter will appeal to us more strongly if we reflect for a moment. The contraction is primarily due to the motor cells of the cerebral cortex. The part played by the cerebellum is not—Ferrier has shown this—save in quite a secondary manner, of a co-ordinating nature.*

Nor can we speak of it as anything else of a tangible nature, unless it be an increasing or reinforcing agency, acting through the medium of the remaining element in muscular activity, namely, chemical change. If this be true of the muscular system, it is probably so in the case of all the tissues the nervous supply of

* See p. 133.

which is connected with the cerebellum, although it is easier to recognise the connection in the case of muscular activity owing to the suddenness and marked character of the changes.

If the reinforcing influence exercised by the cerebellum be due to augmentation of chemical action, how is this brought about? There are in metabolism, as has been shown, two main elements, the one sensory or chemico-sensory, the other vaso-motor. Let us first inquire as to the relations of the cerebellum to the vaso-motor centre in the medulla oblongata. This centre, the most important, though probably not the only one of its kind in the body,* has been located by many observers. It is said to extend from about 3 millimetres above the calamus scriptorius to within 1 millimetre posterior to the corpora quadrigemina,† corresponding, according to Dittmar, to the anterior portion of the lateral tracts, in which are scattered the ganglionic cells of the upper olive (Van Deen) or the antero-lateral nucleus (Clarke). According to Bechterew, a well-marked bundle of fibres passes from the cerebellum to the upper olive, a portion of them reaching it

The cerebellum as a reinforcing organ.

* Ferrier (*loc. cit.*, p. 100), in dealing with this point, states that the bloodvessels depend largely on the spinal centres, the destruction of which, after that of the centre in the medulla, causes further dilatation. As authorities he cites: Lister, 'Philosophical Transactions, 1858'; Goltz, 'Archiv für Physiologie,' *bd.* viii., 1874; Vulpian, 'Leçons sur l'Appareil Vaso-moteur,' 1875.

† Ferrier, *loc. cit.*, p. 100.

Its relations to the vaso-motor centre.

directly, and a portion through the trapezium.* This seems to bring the cerebellum into very close connection with the vaso-motor centre, and, when one considers that its peduncles enclose, so to speak, the whole of that part of the medulla oblongata to which vaso-motor functions are attributed, and that within the same area are to be found the nuclei of almost all the cranial nerves, it becomes evident that this portion of the spinal cord is the seat of some of the fundamental vital processes. One is, therefore, inclined both on general and on special grounds to believe that the cerebellum is very closely connected with the vaso-motor mechanism, and, if there be any truth in this supposition, it enables us to establish an important link between the great cells of Purkinje or 'increase of impulse' cells and the vaso-motor effects which always accompany an augmentation of functional activity in any region of the body whatsoever.

Does the cerebellum influence chemical action directly?

Allusion has already been made to the fact that secretory action may be produced in the submaxillary gland by direct nervous stimulation irrespective of vaso-motor impulses, and it has been demonstrated by Bernard, Heidenhain, and others that the nervous system exercises a direct influence on secretion apart from vascular action.† Secretory activity has been caused even in the sweat glands of amputated limbs,‡ whilst violent perspiration is sometimes accompanied by pallor of the skin, indicating contraction and not

* Bechterew, *loc. cit.*, p. 393.

† Ferrier, *loc. cit.*, p. 83.

‡ *Ibid.*, p. 84.

dilatation of the small arteries. If, therefore, the reinforcing influence of the cerebellum be exercised through the medium of chemical action, there is a strong presumption in favour of the view that it either contains chemico-sensory cells or is directly connected with those cells and fibres in the cerebral and spinal systems by which metabolism is governed. That portion of the cerebellum which it seems most natural to regard as the connecting-link in these processes is the molecular and cortical layer, and the fact that certain portions of it do correspond functionally to certain parts of the body gives support to this supposition.

Although the nervous system, as we have just seen, undoubtedly exercises a controlling and stimulating influence on the processes of metabolism, yet the opinion is generally held that trophic nerves, the sole function of which is to act in a nutritive capacity, do not exist. This requires a moment's consideration. On the one hand it would be difficult to extend the functions of those fibres which govern the secretory processes in the submaxillary gland, whilst on the other hand a motor fibre to a muscle is not one whit less a nerve of chemical action than a nerve, let us say, to the intestines. Chemical change is, indeed, in a greater or less degree implied in all physiological action. The gland builds itself up and breaks down under the influence of nervous action just as the muscle does. Probably all nerves are to some extent, and the great majority are to a very great extent,

Chemical
action as a
constant
element in
nervous
activity.

nerves of chemical action. But the cardinal fact in the whole problem is the sudden, frequent, diverse and great variations in the intensity of this chemical action. This it is which renders a reinforcing organ, such as the cerebellum undoubtedly is, a physiological necessity in the animal economy. If we but look at it in this light we can without any difficulty account for all that is known concerning it—for its coordinating and equilibrium controlling functions, for the defective character of these after its removal, for the possibility of the performance of analogous functions in its absence, and for the state of malnutrition and death which almost without exception occur. Should not this suffice to convince us that the cerebellum is in reality, as just stated, a reinforcing organ to the rest of the nervous system?

We have dealt hitherto with nutrition, and from this part of our subject we now pass to consider briefly the dynamic aspect of reproduction.

CHAPTER III

HEREDITY

Generation is a continuation of growth—The cause of the normal hypersensibility of the testis and ovary—Dynamic impulses bear the character of the parts from which they proceed—The bed-rock of the dynamic theory—The translation of the influence of regional environment through the nervous system to the testis and ovary—Evidence of dynamic elements in the spermatozoa and ova—The transmission of acquired character—The dynamic transmission of syphilis—The influence of a previous impregnation—The determination of sex.

NUTRITION is, if one may so express it, stationary growth. ‘Generation,’ said Letourneau, ‘is so much a continuous growth that its processes are identical with or analogous to those of growth.’ In dealing with the nutritive or metabolic processes of the body two kinds of force were defined, the electro-chemical force, or that of atoms and of ether, and the nervous force. In the problems connected with reproduction these factors again recur for the simple reason so well expressed by Letourneau, ‘that generation is a continuous growth.’ The primary impulse in reproduction comes from the tissues, and is transmitted

Generation is a continuation of growth.

through the nervous system, which is the great link between the parts of the parent and those of the child. The very act of procreation is essentially nervous. It is characterized by a degree of nervous excitation which is almost without a parallel, and the consequence of which, when of too frequent occurrence, is in the highest degree prejudicial to the general nutrition of the body.

The cause
of the
normal
hypersen-
sibility of
the testis
and ovary.

It will be understood that the most excitable part of the nervous system is that which is most easily affected by vibrations generally. When a person has a weak spot, let it be the lungs or the stomach, or the kidney, or the facial nerve, anything such as a chill which disturbs the general health acts with double force on the nerves of that particular part, whichever it may be, and causes a greater amount of irritability or vibratory activity than elsewhere. Now, it is very natural to suppose that the excitability of the nerves to the sexual organs should communicate itself in the first place and in the highest degree to those parts of the nervous system which are functionally most closely related to them—that is to say, to the nerves, to the testis, or to the ovary. Thus it happens that these nerves and the centres in the spinal cord on which they depend are under normal conditions also more excitable than other portions of the nervous system. It follows, therefore, that whenever any action takes place in other parts of the nervous system—or, for the matter of that, in the tissues with which it is connected—there is a greater or less

vibratory movement or reaction in the nerves and nerve-cells of the aforesaid organs; indeed, it is scarcely more, if at all, surprising that a transmission of this kind should take place in the case of a part of the nervous system which is normally hypersensitive than in that of a part which under pathological conditions is frequently so. It is true that reaction in the latter instance may sometimes be caused indirectly through the altered condition of the blood or in other ways, but this does not apply to all cases. Thus when, as sometimes happens, a sensitive person will cough or sneeze at the mere opening of a door, we must attribute this to an excess of sensibility or readiness to vibrate in certain portions of the nervous system—in other words, the effect produced is primarily dynamic. So perfect a conducting medium is the nervous system that no form of transmission need be a cause for wonder. The well-known operation of Paul Bert on a rat's tail and many other instances prove the truth of this statement, and the conditions being—as it is clear they are—permanently favourable, we may be sure that a channel for the passage of what one may term hereditary impulses always exists.

Dynamic effects proceeding from various parts of the body would each bear a certain character depending on the conditions which gave rise to them, since force is always influenced to some extent by the matter through which it passes or from which it issues. The study of sound furnishes us with some

Dynamic impulses bear the character of the parts from which they proceed.

striking examples of such reactions. When the bow of a violin is drawn across the strings force passes along them and away, carrying with it and communicating to the air, and through the latter to the human ear and brain, the peculiar characteristics resulting from a certain length, thickness, and degree of tension. The string has acted as a mould for the force. It has imbued it with its properties. If we wish to penetrate still deeper into the problem we may say that it is the force inherent in matter which has reacted on the force passing through it. So it is with the essential parts of all musical instruments, and so also with the tissues of the body. All forms of force are alike in this respect: they are all influenced by the matter from which they proceed.

The bed-rock of the dynamic theory.

When one reflects that the character of all substances, whatsoever be their origin, is determined by the degrees of force by which their atoms and molecules are held together, when one considers that change of shape in any given mass can result only through the addition or subtraction of force, the real meaning and importance of this factor in physiological processes will become apparent. In order that the various parts of any organism should be reproduced it is absolutely essential that they should be represented in some way in the spermatozoa or ova, as the case may be. If there be no link between them no reproduction can take place. Does this imply that each kind of tissue is represented by a cell, or a part of a cell, or a certain number of molecules in the

spermatozoon or the ovum? Not at all. That which is essential is that the spermatozoon or the ovum should constitute foci of influences or impulses proceeding from every tissue, and representing each not only specifically, but *in extent, in shape, in actual condition*. It is clear that the shape and conformation of, let us say, the nose, the brow, the chin, could not by any possibility be transmitted from parent to child unless the force by which this is brought about corresponded to each of these parts, not specifically, but absolutely. In other words, the various cells of which the nose, the brow, and the chin, are composed are represented in the spermatozoon not as single types of cells, but as collections of individual cells. Only by force—and in this case by physiological force corresponding exactly to the mould in which it is generated—is it possible to produce or reproduce shape. This is the bed-rock on which the dynamic theory of heredity rests.

Attention has been drawn to the fact that the motor nerves are essentially nerves of chemical action, and in this respect all other nerves may be said to resemble them to a greater or less extent by reason of the metabolism which constitutes an essential part of their environment, both when functionally active and when at rest. But whether the control which the nervous system exercises on metabolism is chiefly through the sensory nerves and cells, or chiefly through the motor nerves and cells, or through a combination of the two, it is difficult to say, though

The transmission of the influence of regional environment through the nervous system to the testis and ovary.

combined action seems to be the most probable hypothesis. One thing, however, appears certain: the nerve-cells, whether they be motor or sensory, and whether their fibres be afferent or efferent, vibrate strictly in measure and in accordance with the chemical processes which are taking place. Further, the effects of this vibration are felt in other parts of the nervous system besides the specially active cells, so that any other cells ready or inclined to vibrate would quickly do so in response to, and in accordance with, the stimulus. The argument, therefore, runs thus: Chemical force is liberated in the processes of physiological action and tissue change. Force will inevitably travel most readily along the lines of least resistance or of greatest conductivity, that is to say, along the nervous channels, and as it does so it will stimulate most easily the most excitable centres, which are the normally hypersensitive centres controlling the generative organs. These in turn will vibrate in measure and in agreement with the nature of the stimuli reaching them from every part of the body and due to metabolic action. In such a statement, it will be understood, allowance must be made for counteracting influences, which, however, though they modify, do not essentially alter the normal conditions.

The part which the cerebellum plays in the reproductive processes is the same as in other forms of physiological action, namely that of a reinforcing organ.

The chief anatomical facts respecting the nervous supply of the reproductive organs is given below.*

* After section of the spinal cord above the lumbar enlargement in dogs, all the processes of generation, including parturition, may still take place, which shows clearly that the nervous mechanism of these acts was still complete after the operation. It is, indeed, in the lumbar portion of the spinal cord that the special centres of the various acts included in generation have been located (Ferrier, *loc. cit.*, p. 18). Stimulation of the second and third lumbar nerves in the monkey causes a powerful contraction of the vas deferens (Foster, *loc. cit.*, p. 1510). In the dog and cat fibres passing from the anterior roots of the first and second, and sometimes from the third sacral nerves control the vasomotor mechanism of the sexual organs. In the monkey they proceed from the seventh lumbar and first sacral nerves (*ibid.*, p. 1509). The nerves of the penis are derived from the pudic nerve, which arises in turn from the third and fourth, and sometimes from the second, sacral nerves, and from the hypogastric plexus. The cremaster muscle is supplied by the ilio-inguinal, a branch of the lumbar plexus. The nerves to the testis proceed from the sympathetic system, and are derived from the spermatic plexus, 'a set of delicate nervous filaments which descend upon the spermatic artery from the aortic plexus.' This latter is joined by branches of the lumbar ganglia of the cord. Some fibres reach the testis from the hypogastric plexus, which also supplies the vesiculæ seminales. The nerves of the vagina come from the hypogastric plexus of the sympathetic, the fourth sacral, and the pudic nerves; those of the uterus from the hypogastric and spermatic plexuses, and from the third and fourth sacral nerves. The nerves of the ovaries are derived from the ovarian plexus and from the uterine nerves.

Thus the nervous supply to the reproductive organs is a very complicated nature, and the only links of importance which can be established at present between them and the centre in the lumbar portion of the cord on which they depend appear to consist of those fibres of the sympathetic system connecting, on the one hand, the spermatic and ovarian plexuses, and on the other hand the hypogastric plexus with the aortic plexus. It

The dynamical nature of the reproductive process is further illustrated by the vibratile character of the spermatozoa. Their movements, which are both varied and rapid, are described as those of torsion, reptation, fluttering and spiral turnings. A single spermatozoon will move at about the rate of 2 to 3 millimetres a minute, the rate of progression varying according to the medium in which it happens to be. The vibratile activity is most evident in the middle and tail portions, and some observers assert that it is originated in those parts; but it seems more natural to suppose that the movements are due to molecular vibrations in the head portion—vibrations which are the direct result of the nervous nutritive impulses which have led to the production and the discharge of the spermatozoon. One thing is undeniable: spermatozoa are not merely collections of inert matter. They are the embodiment of forces of the most varied nature, the dynamic specialization of every cell in the body of the parents taken together; and this, it is scarcely necessary to say, is in a certain sense the highest form of specialization it is possible for any tissue to assume.

Evidence
of dynamic
elements
in the
sperma-
tozoa and
ova.

The spermatozoa of all the vertebrate animals show the same vibratile activity. In crustaceans there is an apparent lack of mobility, which, however, is said

seems probable that the plexuses mentioned—the spermatic, ovarian, and hypogastric, control the whole of the vascular mechanism of these parts; nor is it unlikely that they govern secretion respectively in the testis or ovary.

to disappear when the spermatozoa enter the mucus of the uterus. When we descend lower in the scale of creation, in both sexuate and asexuate forms of reproduction the dynamic element is always present. We see it in the simple fission of such organisms as the hydra and vorticella. We trace it again in the segmentation of the ovulum of the aphides, in the swimming zoospores of algæ, in the antherozoids, in the divisions of the cell fecundated by the favilla of the pollen.* Look where we will there is ample evidence that force plays a great and preponderating part in reproduction.

There is a rather prevalent belief that acquired characteristics cannot be transmitted from parent to offspring. If a man, it is said, lose a finger, or a hand, or an arm, his children will not on that account show any such deficiency. Doubtless in such a case a child might inherit its fingers, or hands, or arms, from its mother and not from its father, or partly from the one and partly from the other, the positive influence of the former naturally outweighing the negative influence of the latter. But even in the most improbable event of both parents having lost the same finger or hand, there is, according to the dynamic theory of heredity, a possibility of their issue being quite normal in this respect. Though the parts might be wanting it does not necessarily follow that the nerve centres on which they once depended have undergone degeneration. A sensation of pain is often

The transmission of acquired characteristics.

* Letourneau, *loc cit.*, pp. 316-318.

referred to limbs or portions of limbs which have been entirely removed by the hand of the surgeon. The nerve centres, therefore, which correspond to the severed parts still vibrate in the old manner, and if this is so in regard to pain, it may be assumed that a somewhat similar state of things would obtain in respect to the transmission of hereditary impulses.

Positive as well as negative influences deserve some consideration. The former may be either good or bad: they may exceed the normal degree of intensity, or they may fall below it. It may possibly be that when the influences proceeding from both parents are opposed they act as mutual correctives, but, so far as we know, there is no evidence on this point. It may be also that a perfectly normal influence on the part of one parent is sufficient to counterbalance abnormal influences on the part of the other; this, however, would seem to be more probable were the latter deficient in intensity. But there are many abnormalities in the mode of functioning of the nervous system which become, as it were, grafted on to it, and are very frequently reproduced by hereditary transmission. Let us suppose, for instance, that a couple happens to be living in a very relaxing locality, and that as a consequence the walls of their arteries become somewhat flaccid, the circulation slow, and the nerve-power generally diminished. Children born from them under such conditions would probably show some signs of languor and lack of vitality. On the other hand, let us suppose that, as a result of long

exposure, a man and his wife both contract marked chronic bronchial irritability. In such a case the chance of their children being similarly affected would be very great. If we admit, as we certainly must, the transmission from parent to child of peculiarities of form and structure, we cannot by any method of reasoning limit such transmission to external appearances only. All that applies in this respect to each part as a whole must inevitably apply to its minute conformation and general condition also, to the individual cells as well as to the collection.

When the abnormal state of any tissue assumes a chronic character, so that it reacts upon the nervous system, and causes it to function in an irregular manner, it is very likely to be transmitted. The transmission may not be in the same degree, and there is always the possibility of a child inheriting the character of this or that part or organ from one parent only, but there can be no doubt as to the transmissibility in many cases of acquired characteristics. Weaknesses which have become grafted, so to speak, on to the nervous system, even though not causing suffering at the time of generation or affecting the parent to any appreciable extent, may nevertheless be transmitted to the offspring. This is notably the case in syphilis, the whole character and peculiarities of which are easily explained if we look on it as modifying the nutritive action of the nervous system in a katabolic sense, and as being frequently transmitted as a nervous affection of that nature to

The
dynamic
transmis-
sion of
syphilis.

The influence of a previous impregnation.

the child. Under these conditions the immunity of the mother of a child affected by congenital syphilis and the transmission of the disease from a father who to all appearance is free from the virus* are not only explicable but natural events. Hereditary effects of the kind just described may be compared to those which are due to the influence of a previous impregnation, for in both cases it is a question of the recurrence of a past state or of a past mode of vibration of the nervous system. In this respect the following examples taken from a work by Miles are of very great interest† :

‘In 1815 a chestnut mare, seven-eighths Arabian, belonging to the Earl of Morton, was covered by a quagga (a species of zebra); the hybrid produce resembled the sire in colour and in many peculiarities of form.

‘In 1817, 1818, 1821 the same mare was covered by a very fine Arabian horse, and produced successively three foals, and, although she had not seen the quagga since 1816, they all bore his curious and unequivocal markings.’‡

‘It is stated, on the authority of Mr. William Goodwin, veterinary surgeon to Her Majesty, that “several of the mares in that establishment” (royal stud at Hampton Court) “had foals in one year which were by Actaeon, but which presented exactly the

* Osler, ‘The Principles and Practice of Medicine,’ p. 238.

† Manby Miles, ‘Stock Breeding,’ p. 255.

‡ ‘Philosophical Transactions,’ 1821, p. 20.

marks of the horse Colonel—a white hind fetlock, for instance, and a white mark or stripe on the face ; and Actaeon was perfectly free from white. The mares had all bred from Colonel the previous year.' ”*

‘ A colt, the property of the Earl of Suffield, got by Laurel, so resembled another horse (Camel) that it was whispered—nay, even asserted at Newmarket—that it must have been got by Camel. It was ascertained, however, that the only relation which the colt bore to Camel was that the latter had served his mother the previous season.’ †

‘ Mr. George T. Allman, of Tennessee, gives the following case that came under his own observation : “ I bred a bay mare, black points to Watson, a son of Lexington, who is a golden chestnut, large star, both hind and near front ankles white. After dropping the foal to Watson, I bred the same mare to my saddle-stallion, Prince Pulaski, a very dark chestnut, no white save a very small star ; this produce was a facsimile of Watson in every particular.” ’ ‡

‘ Alexander Morrison, Esq., of Bognie, had a fine Clydesdale mare which, in 1843, was served by a Spanish ass, and produced a mule. She afterwards had a colt by a horse, which bore a very marked likeness to a mule ; seen at a distance everyone set it

* *Farmers' Magazine*, vol. xxxv., p. 130.

† *Journal of the Highland Agricultural Society*, 1857-1859, p. 26.

‡ ‘ Rural Sun,’ as quoted in *National Live Stock Journal*, June, 1877, p. 245.

down at once as a mule. The ears are $9\frac{1}{2}$ inches long, the girth not quite 6 feet, and stands above 16 hands high. The hoofs are so long and narrow that there is a difficulty in shoeing them, and the tail is thin and scanty. He is a beast of indomitable energy and durability, and is highly prized by his owner.’*

‘A similar case is recorded by Dr. Burgess, of Dedham, Massachusetts, who says: “From a mare which had once been served by a jack I have seen a colt so long-eared, sharp-backed, and rat-tailed that I stopped a second time to see if he were not a mule.”’†

‘A pure Aberdeenshire heifer was served with a pure Teeswater bull, by which she had a first cross-calf. The following season the same cow was served with a pure Aberdeenshire bull; the produce was a cross-calf, which, when two years old, had very long horns, the parents being both polled.’

‘Mr. Darwin cites the following case from the *Philosophical Transactions*, 1821: “Mr. Giles put a sow of Lord Western’s black and white Essex breed to a wild boar of a deep chestnut colour, and the pigs produced partook in appearance of both boar and sow, but in some the chestnut colour of the boar strongly prevailed. After the boar had long been dead the sow was put to a boar of her own black-and-white breed—a kind which is well known to breed very true, and never to show any chestnut colour—yet from this

* Goodale, ‘Principles of Breeding,’ p. 48.

† *Country Gentleman*, 1870, p. 426.

union the sow produced some young pigs which were plainly marked with the same chestnut tint as in the first litter.”*†

‘Professor Agassiz states that he had “experimented with a Newfoundland bitch by coupling her with a water-dog, and the progeny were partly water-dog, partly Newfoundland, and the remainder a mixture of both. Future connections of the same bitch with a greyhound produced a similar litter, with hardly a trace of the greyhound.”’†

‘A white woman, who has had children by a negro, may subsequently bear children to a white man, these children presenting some of the unmistakable peculiarities of the negro race.’‡

These are only a very few of the cases given in the work already cited, which, indeed, are so well authenticated, so numerous, and drawn from such independent sources, that it is quite impossible to disregard them. Some writers, and amongst them Dr. Carpenter, have attributed the influence of a previous impregnation partly to the mental impression and partly to modifications in the nature of the blood. There is, however, no evidence whatever in favour of the latter suggestion, whilst it is very

* ‘Animals and Plants under Domestication,’ vol. i., p. 485.

† *Agricultural Report of Massachusetts*, 1863, p. 57.

‡ ‘Physiology of Man,’ by Flint, vol. v., p. 347; see also ‘Human Physiology,’ by Carpenter, p. 970; *British and Foreign Medico-Chirurgical Review*, July, 1863, p. 183; Darwin’s *Animals and Plants under Domestication*, vol. ii., p. 485, note.

improbable that the mental impression alone would suffice in all cases to account for the results actually obtained. Others, like Professor James Law, have suggested that the impregnated ovum impresses its own character on the mass of the decidua, and through this on the maternal placenta, and that this in turn impresses its character on the decidua and embryo of the next succeeding generation. The objection to this, a partial one, is that the decidua itself is renewable. We must therefore go further than the last observer, and search for some other sort of tissue in which the dynamic impulses embodied in the spermatozoa and in the foetus can be stored up in the system until they are again rendered active. Can this tissue be any other than the nervous system? Do we not know, as well as we know anything in physiology, that the nervous system is a great storehouse of impressions or impulses? Does not the womb and all its contents constitute a most notable portion of the environment of the nervous system, a portion the more remarkable because of the intensified activity which is common to both during the period of gestation? Does not the nature of the metabolism, going on in any part of the body, influence the nervous system often as a whole? If in this case there is no direct nervous connection between the foetus and the nervous system of the mother, are we to deny that impulses or dynamic impressions may reach the latter through the medium of the ether, which permeates the womb as it does

every other part of the organism? Lastly, is not this recurrence of the former dynamic state really analogous to memory, and therefore entirely in accordance with the habitual mode of functioning of the nervous system? Darwin, as Miles remarks, seemed to have taken the view that the male element in reproduction may act directly on the mother form. 'The male element,' he says, 'not only affects, in accordance with its proper function, the germ, but the surrounding tissues of the mother plant.'* And again: 'The analogy from the direct action of foreign pollen on the ovarium and seed-coats of the mother plant strongly supports the belief that the male element acts directly on the reproductive organs of the female, wonderful as is this action, and not through the intervention of the crossed embryo.'†

If we regard reproduction as a whole primarily and chiefly as a dynamic phenomenon, we shall be the less inclined to underrate the influence to which Darwin draws attention. At the same time, however, we must not forget that the spermatozoon itself is essentially a vibratile body, nor overlook the fact that reproduction may sometimes take place without actual connection of the reproductive organs. One thing is certain: the substance of the spermatozoon or ovum is secondary to the force which animates them. There is probably no difference of a chemical order between the spermatozoon and ovum which unite to

* 'Animals and Plants under Domestication,' vol. i., p. 483.

† *Ibid.*, p. 486.

form one child and those which unite to form another, but there are very important dynamic differences, and it is only when the subject is approached from this point of view that the various problems connected with it can be treated with any hope of success.

The deter-
mination
of sex.

Hereditary transmission, as applied to this or that part, probably depends on the conductivity of the parental nervous system and on the force of the nutritive or metabolic impulses, and in this way one must suppose that the sex of the offspring is determined. There are, however, many secondary factors in prepotency which are both variable and difficult to ascertain. Under these circumstances it is manifestly absurd to pretend, as some do, that a child always inherits certain traits or characteristics from its mother and others from its father. The utmost that can be said is that women are more sensitive, as a rule, than men. Greater sensibility may be regarded as equivalent to greater conductivity, but not to greater transmitting power. As already said, there are other factors to consider, and any generalization beyond this, from whatever quarter it may come, should be received like an old woman's tale.

The moral aspect of heredity may be expressed in a very few words. When any form of nervous vibration attains a high degree of intensity there is considerable likelihood of its being transmitted from parent to child. When thus transmitted, unless counteracted, it will often manifest itself in a still more pronounced manner; so that acts which in one generation may

be regarded as mere peccadilloes or errors of judgment may yet lead, under slightly unfavourable conditions, to the direst results in succeeding ones. To attempt to lay down any rules by which the degree of culpability attaching to any individual can be determined is entirely vain. The utmost we can say in a general way is that our deeds, be they white or be they black, are written in the vibrations of our nerve-cells and in those of our descendants.

THE END



